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1

Dr. Buckminster Brown

ROBERT S. SIFFERT, M.D.*

"Orthopaedy" in America during the mid-19th century was merely an infant offspring of the well-established specialty in Europe. A handful of surgeons, turning their attention to musculoskeletal problems, struggled for recognition by their colleagues. They argued that many uncorrectable deformities resulted "owing to this want of [specialized orthopaedic] attention on the part of the physician" and that "parents were [erroneously] continually receiving the assurance that their children will in time outgrow their deformity."[13] Many well-conceived and well-executed mechanical and surgical procedures failed to produce the desired results because of clumsy methods, poor follow-up, lack of attention to detail and rehabilitation.

Who can say whether it was the challenge of this new specialty, dedicated to the task of mending "uncorrectable" deformities, whether it was the influence of his father who practiced orthopaedy, or whether it was the existence of his own severe kyphoscoliotic deformity that determined Dr. Buckminster Brown's destiny.

Born into one of Boston's most illustrious families, Dr. Brown traced his ancestry to John Warren, who arrived in Salem on June 12, 1630, on the *Arabella;* to his great-grandfather Joseph Warren, who fell at Bunker Hill; and to his grandfather, Dr. John Warren, "Surgeon of the Revolution," who had taken an active part in the Boston Tea Party, was present at the Battle of Lexington and later was one of the founders of Harvard Medical School. His own father, Dr. John Bull Brown, is credited with having introduced the specialty of orthopaedy to America when he established a private hospital, the Boston Orthopedic Institution, in 1838. Although several surgeons were intrigued by the possibilities of correcting deformities, John Bull Brown devoted himself entirely to orthopaedy, being the first in America to describe experiences with subcutaneous tenotomy in the correction of clubfoot. Through his ingenuity in devising mechanical apparatus, he developed a wide reputation in treating wryneck, clubfoot and spinal curvature, his case records boasting patients from areas as remote as the Sandwich Islands.

Dr. Buckminster Brown was born in 1819. In childhood he contracted Pott's disease along with its kyphoscoliotic sequelae. His shut-in existence and avoidance of publicity occasioned by ill-health that continued throughout his 72 years of life, and probably self-consciousness about his deformity, probably accounted for his devotion to his work, his books and his patients. His obituary in the *Boston Daily Advertiser* on Wednesday morning, January 20, 1892, stated:

> . . . though constrained by sickness and infirmity to comparative seclusion, his lot was borne with a quiet and unassuming fortitude that revealed the germs of a greatness which he was forbidden to display on a wider or more conspicuous field. His mission was to unfold the heroism of enforced retirement and to display the sure rewards, both professional and other, that could be gained in spite of pain and weakness, and of the depressing weight of obstacles that might

* New York, N. Y.



FIG. 1. Dr. Buckminster Brown. (Mayer, Leo: J. Bone & Joint Surg. 32-B:485)

have daunted the bravest. There were not many that knew, still fewer that witnessed, the patient and persistent struggles of a spirit so worn and yet so forceful, which ever pressed on and on to the end, breasting the stream at its highest, though there was no crowd of applauding spectators and little testimony of approval but its own good conscience. It is of such stuff that martyrs were once made and even now they are occasionally unveiled for our learning, though they die not at the stake or on the arena amid a cloud of witnesses.

The *Sunday Herald* on December 27, 1891, said:

> To see the doctor and his tall, fair wife together might have suggested an incompatibility from the striking physical contrast, which instead of being in any degree true, only emphasized a very rare and affectionate union.

Through his favorite expression, "Genius is the talent for taking pains," he stressed the need to develop a keen sense of touch, which, coupled with his "refined and sensitive nature," mechanical ability, remarkable surgical dexterity, as well as his delicate and compassionate handling of a case, suited him admirably as the Father of Children's Orthopaedics in America.

After graduation from Harvard Medical School in 1844 he went abroad to study orthopaedy under Little, in London; Guerin and Bouvier, in Paris; and Stromeyer, in Germany. Also he wished to

> carefully examine the great variety of surgical instruments and apparatus there employed . . . with a view to their introduction into our own country.[14]

His respect for and his devotion to his European teachers continued throughout his life. Through correspondence and reading he maintained his contacts with the European orthopaedists, and, in all his papers, whenever arguing a principle or a procedure, his discussions were profuse with quotations and references to European and, occasionally, American orthopaedists. As though describing a personal inner passion, Dr. Brown was most impressed that

> in France, more than other countries, a medical man . . . as it were by a natural impulse, seizes upon some one of . . . its branches and . . . dives into its depths with a determined vigor, a hearty earnestness of inquiry, and unsparing of his labor, brings it . . . nearer perfection.

On his return to Boston in 1846, Dr. Brown entered general practice but soon joined his father at the Boston Orthopedic Institution (or Hospital for the Cure of Deformities of the Human Frame) for the exclusive practice of orthopaedy, postponing marriage until his 45th year. By their own admission, the institution was

> a large and commodious house in a healthy location. . . . The treatment is in conformity with the most modern improvements in Europe; the junior surgeon of this Institution [Buckminster Brown] having recently visited all the Orthopedic Institutions of distinction in England, France and Germany, for the purpose not only of gathering statistical facts of the state of Orthopedy in the Old World but also to form an acquaintance with the first surgeons, and their modes of practice, and of establishing a correspondence with them, now gives to the Boston Institution the very important advantage of re-

ceiving the earliest information of all improvements there made in this Branch of Surgery.[13]

The majority of patients admitted to the Boston Orthopedic Institution were not infants, but rather children and adults whose deformities were untreated, maltreated or accepted as uncorrectable for years. The technics established at the Institution for correction of clubfoot and other deformities were applied to children and adults alike, one case of clubfoot correction being accomplished at the age of 72. In his repeated plea for early diagnosis, Dr. Brown warned his contemporaries against "postponement of treatment until the cure becomes extremely difficult, and tedious, or impossible." He reported his results of early management of foot and spine deformities to the Massachusetts Medical Society, Suffolk District Medical Society and the American Social Science Association, and published them in the *Boston Medical and Surgical Journal*, the *American Journal of Medical Sciences* and the *North American Review*, as well as in private pamphlet form. His detailed case reports were evidence of hospital records meticulously maintained. His frequent references to long-term postoperative observations demonstrated the importance that he placed upon careful and thorough follow-up.

Dr. Brown's most important contributions to pediatric orthopaedics were during his incumbency as surgeon at the Good Samaritan Hospital (1863-1880), where he established a department of orthopaedic surgery consisting of 24 beds. He remained in charge of the Service for 17 years, when "he resigned his place [to become Consulting Surgeon until his death] because he felt himself unable longer to attend to our patients."[1]

His devotion to the problems of children—his efforts extended to all handicapped children—and his complete understanding of the limitations imposed by a handicap in the rehabilitation of the disabled child were inherent in his nature. On his return from Europe in 1847 he sparked the State Legislature in Massachusetts to appoint a committee to study the "number of idiots in our commonwealth, together with their situation and prospects." He pleaded that idiots and cretins deserved the opportunity to develop in a healthful and sheltered setting. He described how many throve in general happiness, health, attitude, even to the extent of learning "to speak and receive religious and moral ideas, . . . read and write . . . and learn a trade."[4] How well accepted this would be today in a discussion of our current vocational and educational ideas on the rehabilitation of handicapped children, particularly those with cerebral palsy and other severe disabilities!

In the same year—1847—he wrote about his studies and observations of "ethereal inhalation,"[3] describing in great detail his European experiences with the anesthetic. He stressed not only its use in surgery but its synergism with other drugs to alleviate pain and suffering. His inquiry into the physiology of the shocklike effect of overnarcotism with ether is an example of his experimental mind. He argued the cause of vivisection by asking:

[illegible]
pain, or even the infliction of a greater degree of discomfort than occurs in drowning, serve for the advancement and well-being of humanity?

He was intrigued by the effect of ether on the brain and the spinal centers, the sparing of will, recognition and memory in analgesic doses, and the possibility that a separate organ might exist in the brain, "appropriated peculiarly to the sensation of pain" that alone was put to sleep under the effect of ether. In his personal animal experiments he tested successfully the effect of an electric current as an antidote to overetherism.

Dr. Brown was an inquiring student and a forceful teacher. His publications and speeches were prepared meticulously. They presented a review of the literature to date

and current accepted theories, and were followed by his personal thesis, well documented by clinical observations, logical arguments and case reports. Cases were detailed and illustrated profusely with drawings, and later with photographs of patients and casts. In his articles he was far from modest about his accomplishments and excellent end-results, including testimonial letters from physicians and patients, and was never happy with a procedure unless he could express a physiologic rationale that he could accept.

The correction of clubfoot and the management of spinal deformities were his greatest interests. In his *Hints on the Diagnosis and Treatment of Clubfoot*[9] he controverted the

> generally accepted but unproved theory that talipes is due to a paralysis of certain muscles . . . *a theory adduced dogmatically and without* proof that has never been directed impugned or controverted

His description of the anatomy of a clubfoot and detailed instructions as to the correct method of examination stressed the art of "tactile sensitiveness." To "attain a delicacy of diagnosis" one often depended upon feeling a "feeble, scarcely perceptible rising of the adipose tissue and skin against the finger." In his review of the accepted technics, he was critical of the clumsy methods used and of the application to all patients of any generally accepted approach, his philosophy being that each patient was an individual problem of diagnosis and management. At each stage of progress, re-evaluation is necessary, and treatment must be adjusted accordingly. In his vehement contempt for taping, plaster and static splints, he said that the rigid resultant deformity was the "mischief resulting from keeping a part too long secured in an apparatus." Success of treatment, he felt, depended upon constant manipulation and change of position, which helped to impart tone to overstretched and weakened muscles in the attainment and the maintenance of correction, which was not accomplished by plaster.

Tenotomy, as learned from Stromeyer and his father, was his most useful tool. But he criticized equally strongly the use of surgery alone, regarding the treatment of clubfoot as tenotomy when indicated, followed by *careful and frequent manipulation and* the use of hinged or screw-spring splints or shoes. Without tenotomy he felt that "we are simply thrown back to the ante-Stromeyerian period." Emphasizing that the "abuse of surgery, and not its use, is to be avoided," he blamed failures on its misapplication and inattentive after-care. "The after-care must never be intrusted to unaccustomed hands; success depends upon constant, unwearied personal attention." After mechanical appliances, massage, manipulation, active and passive exercises, and in some cases electricity, accomplished the maximum possible improvement, residuals were again treated by tenotomy and meticulous postoperative therapy: "the sensation imparted by the implicated tendon is to the experienced touch a sufficient indication [for surgery]."

His experiences with clubfoot were applied to contractures of the hip[10] and torticollis.[13] By careful analysis, he demonstrated that the accepted belt and spring method for correction of flexion contracture of the hip merely increased lumbar lordosis with only an apparent effect on the contracted hip. He discarded his own experimental apparatus involving a body brace for complete spine fixation, and decided upon a close-fitting mold to lock the pelvis. Only after surgical release of the contracted tissues was the pelvic mold applied, and correction was attained and maintained by a spring or screw device.

Since most of his patients with torticollis were unrecognized or untreated during infancy, division of the contracted muscle was considered a necessary prerequisite, followed by a dynamic splint to maintain the correction by "acting steadily"[8] on the deformity. Initially, he employed an apparatus of his father's invention; later, he designed

ease with the development of subsequent deformity. He argued that not only did traction, with a pad under the gibbus to correct the deformity, relieve pain, but that in most instances it permitted "complete restoration to health."[7] As in so many areas where Dr. Brown took issue with accepted practice, he was careful to state that no method was applicable in every instance and to outline contraindications.

Even in his later years, Dr. Brown continued to display the meticulous personal attention to detail that was responsible for so many corrections of deformities that had failed at the hands of other surgeons. In his *Double Congenital Displacement of the Hip*,[11] in 1885, he described in detail the reduction, the maintenance and, finally, the rehabilitation over a period of 3 years of the dislocated hips of a 4-year-old girl, exhibiting patience and dedication rare in any human being.

Our sole tangible memorial to Dr. Buckminster Brown's inquiring mind, teaching ability and pioneer spirit in children's orthopaedics, as well as in American orthopaedics in general, is the 50-year-old Dr. Buckminster Brown Professorship in Orthopedic Surgery at Harvard Medical School, established by his own legacy.[2]

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SECTION I

REHABILITATION

2

Disability Evaluation and the Orthopaedic Surgeon*

EARL D. MCBRIDE, M.D.†

The unfavorable result of physical injury is the threshold of disability. Evaluation of disability is of great importance to the orthopaedic surgeon because the greater number of accidental injuries involve the musculoskeletal system. Physical impairment is certain to occur in many of the more serious injuries, regardless of the most efficient treatment Whether a man is self-employed or works for an employer, notable physical impairment may have a profound effect on his future endeavor. The treatment of the injury commands the primary interest of the surgeon. He is accustomed to ceasing responsibility when the injury has reached a state of healing in which there is no more to be accomplished through treatment. But here the treatment that has been given goes on trial. A tendon transplant that has required several operations and many dollars of expense may demonstrate the extraordinary skill of the surgeon, but will it be of benefit in restoring the efficiency of the patient to do his job? An arthrodesis of the wrist may be a beautiful piece of surgical technic, but what will happen when the employer tells the man that he is no longer qualified for his technical trade? The self-employed individual usually accepts the inevitable, and sooner or later he readapts himself to his limitations. When responsibility rests on others for the misfortune of injury, the psychology is different: whatever the injury, or the hurt, he considers that there is someone who owes him something for it, and only a final settlement may suffice to end his mental state of reprobation.

DEFINITION OF DISABILITY

Disability is a term that implies a transformation of the body structures which results in a depreciation of normal ability to perform the functions of established physical accomplishments. Pathologic states which result in disability are:

1. Accidental injuries which result in deformity and joint impairment
2. Hereditary malformations, often previously unrecognized
3. Developmental, metabolic and disease states which result in exacerbation or delay normal recovery
4. New growths or faulty body tissue that prevents normal reaction to injury
5. Inflammatory affections and diseases that influence normal repair.

The subject discussed here is the aftermath of accidental injuries, but the other four causes of disability may well be involved in respect to their causal relation to the injury. It is obvious that the medical evaluation of disability is a broad subject and should not be dealt with lightly. Almost every day the orthopaedic surgeon is called upon to risk his reputation on the expression of an opinion in some case in which the extent of disability is in dispute. Extensive training and a high degree of orthopaedic knowledge may not suffice to prevent em-

* Read during the meeting of the Association of Bone and Joint Surgeons held in Norfolk, Va, April 2, 1955.

† Oklahoma City, Okla

barrassment and confusion on cross-examination in court.

There is only one answer to this situation: if the surgeon expects to accept such responsibilities, he should be prepared to deal with the subject of disability evaluation as expertly as he is trained to deal with his usual problems of orthopaedic surgery. It is not a difficult subject; however, it requires the same special study and experience as any other scientific subject. He must recognize the necessity of a competent and systematic analysis of every phase of the claimant's case, and he must have some definite method of appraising and evaluating the percentage of disability. Some of the more important factors in approaching the subject of disability follow.

PARTIAL DISABILITY VS. PERMANENT DISABILITY

Often it is necessary to evaluate the permanent disability before the case has reached its maximum improvement, with the result that the disability is rated much higher, or lower, than is justified. Permanent disability may be defined as a permanent and irreversible state of body impairment which limits the normal capacity of the individual to perform useful work. It may be partial, or total—loss to a part of the body or to the body as a whole. Permanent total disability implies the impairment of mind or body sufficient to render it impossible to follow a gainful occupation throughout life. Permanent partial disability implies the ability to follow a gainful occupation to a limited degree When the progress of the case has not reached its maximum extent of improvement, the disability is still temporary, and often an estimate must be made of the length of time until maximum improvement will be reached

READJUSTMENT

Many times the injured employee is dismissed by his doctor as not being in need of further active treatment, but the patient returns to his employer to find that residual weakness, instability or stiffness does not permit him to do his regular job. If the doctor states that he can do light work, the employer may say that he has no light work. Often this situation results in a settlement which is precarious to his readjustment. Some form of rehabilitation must take place. The man may secure a job elsewhere in which the impaired parts of his body will not impede his ability to work. Continuation of physical therapy and rehabilitation measures over too long a period may little more than soothe the tendency to psychoneurosis and exaggeration. Pride in normal physique is important to most individuals. The attitude of defeat and mental suffering over the fear of being crippled may interfere profoundly with rehabilitation until self-confidence can be restored. The time to start rehabilitation is at the beginning of treatment. It is the responsibility of every surgeon to soothe the anxiety and to forewarn of the inevitable.

APPROACH TO THE EVALUATION OF DISABILITY

How is disability to be evaluated by the physician? How can the performance of this necessary medical duty carry with it the dignity and the respect of the medical profession? The obvious answers to these questions are that the subject should be established on a scientific basis. The diagnosis of the extent of disability should consist of similar steps of reasoning essential to any medical diagnosis. There should be no place for speculation, a sympathetic ear for favoritism or haphazard guessing. The extent of disability should not rest alone on first impressions resulting from striking roentgenographic disclosures, serious-appearing anatomic changes or bizarre and exaggerated subjective complaints A doctor never should become classified as overconservative, *liberal or inconsistent*

For a number of years the author has proposed the use of a methodical, systematic and rational method of evaluating disability. Many consider that it is too difficult to un-

derstand or to apply such a system. No apologies are made in this respect. Any medical or scientific subject deserves study and special training to develop reliability. The subject of disability, which is quite an extracurricular subject, so far as the study of medicine is concerned, is no exception. The following is a brief explanation of a proposed method which, if followed, will at least lead the physician to a comprehensive view of all the aspects of a case that is to be evaluated for the extent of disability.

THE PRINCIPAL FACTORS OF DISABILITY

There are two principal components in the evaluation of disability: (1) functional deficiency; and (2) physical impairment. The loss of function is the result of the physical impairment, but *the evaluation of* disability involves the proportional weighing of the influences of both components.

Functional Deficiency

Loss of function must be rated in the light of the remaining efficiency with which the disabled individual can perform useful actions of work. When a person is partially and not totally disabled, it is as important to estimate what he *can* do with the parts of his body that remain normal as to determine what he *cannot* do because of his disability. *In order to determine function, it is necessary* to establish the various factors that make function possible or that limit it. The extent of physical disturbances may be elicted through physical examination, but the extent of function, or loss of function, may require exhaustive application of actual or imaginary tests.

The author has suggested seven factors of function which are fundamental * They are: (1) quickness of action, (2) co-ordination; (3) *strength*; (4) security; (5) endurance; (6) safety; and (7) prestige of physique for employment.

Quickness of Action. This implies speed *of movement in use of the body.* What is the degree of alertness? With what acceleration can acts of function be initiated?

Co-ordination. This is necessary for smooth, methodical efficiency and expertness. Synchronizing dexterity and good control contribute to skilled proficiency.

Strength. This is a variable factor according to the normal physique of the individual that is quickly diminished through inactivity following injury. Restoration of strength may require an unexpectedly long period of time; therefore, the permanent state should not be judged prematurely.

Security. This is a factor of trustworthiness and confidence. Normal acts of function are accomplished without conscious effort, and when this faculty is affected the result is uncertainty and insecurity.

Endurance. This involves stability and continuous activity without unnecessary interruption. When routine work requires persistent activity with vigorous application of effort, there *is no toleration of the exceptional* elements of fatigue, exhaustion or *weariness.*

Safety. This is a factor involving self-protection and no hazard to others. The inability to jump or to dodge quickly, or the possibility of letting go too quickly, should classify a man as an increased risk to himself or to others.

Prestige of Normal Physique. This is a factor of employability, but also it may greatly influence mental and neuromuscular equilibrium. Pride of physique is a natural attribute of personal confidence which, when crippled, may depreciate initiative and destroy ambition of attainment. Employers have become somewhat more tolerant toward employment *of the handicapped* person; however, a broad barrier of resistance still is encountered in returning an obviously disabled person to work.

The Physical-Impairments Component

The physical impairments that may occur in connection with the subject of disability evaluation are as numerous as the various

* McBride, Earl D Disability Evaluation, ed. 5, Philadelphia, Lippincott, 1953.

parts of the body that may become affected through accidental injury or disease. There are as many variations in body response to injury as there are systemic reactions and abnormal physical influences that may have a causal relation to injury. The physical disorders elicited through a thorough examination represent the extent to which the body has been altered from its normal state. They are an integral part of the disability. They represent the physical damage exclusive of the loss of function which results through their existence. In some instances, extraordinary physical damage can occur without producing an equivalent amount of lost function. Likewise, a minor physical damage of more or less minor degree may totally prohibit the ability of a man to return to his regular trade or occupation.

The physical impairments component of disability may be summarized under five principal units: (1) anatomic mass damage; (2) clinical manifestations; (3) job-restoration restrictions; (4) restrictions of working conditions; and (5) reactionary interferences.

The Anatomic Mass Damage Unit. The anatomic mass damage unit of physical disorders includes the destruction or the physiologic or the mechanical alterations found to exist as a result of the injury. They include bone deformity, damage to the back structures, joint pathology, muscle deficiencies, damage to the brain and damage to the vital organs or to any other tissues or structures of the body.

The Clinical-Manifestations Unit. The clinical manifestations unit may be subjective or objective. The former must be weighed carefuly for their actual importance in relation to the disability. The more common factor influencing disability is pain. There is no absolute standard for measuring pain Some individuals exaggerate; in others, the threshold of pain is low. Only the experienced can judge the importance of pain and whether or not it exists at all in certain instances. Loss of joint motion is another clinical finding of great importance. Some even measure the extent of disability to an extremity by the degree of loss of motion. Paralysis, atrophy, ischemia, synovitis, crepitus, suppuration, psychoneurosis, various systemic symptoms and many others may enter the picture.

The Restrictions of Job-Restoration Unit. The surgeon who treats industrial injuries must bear always in mind the importance of the injured structure to the job at which the person is employed. To a skilled laborer who must be minutely accurate with his fingers, an ankylosed joint can be more disabling than an amputation. Not ordinarily is the physician fully acquainted with the skillful requirements of various trades or occupations, but, if he is told which actions of the body are required to do the specific job, he can evaluate the ability of the disabled person to carry these out. The doctor is probably not competent to say whether or not a man can return to work as a plumber, but he is qualified to say whether or not the man can crawl, kneel or climb ladders. He can say whether or not the man can lift heavy or light loads, grip objects of certain size, walk, run or jump.

The Restrictions of Working-Conditions Unit. This unit involves environmental influences that may prohibit the disabled person from working. The temperature influence in excessive heat or cold, exposure to sun or wind, local hazards of slippery footings, irritating grease or dust, the strain of driving, or the effect of rapidly moving machinery or vibrating tools, and many other such situations are to be considered.

The Reactionary-Interferences Unit. Included in this group are the many intangible influences that limit the future endeavors of the disabled individual. They involve mental, social and economic impediments, many details of which cannot be observed and are impossible to detect on physical examination. The age of the individual is included in this unit; also his social and educational status. Unpredictable exacerbations of symptoms which the physcian feels are likely to occur may be included, together with many other intangible factors

THE USE OF THE FORMULA FOR EVALUATION

It is a great satisfaction to have a sound basis upon which to base a medical opinion that involves a monetary award for a claim. Usually, the purpose of examining a claimant is to determine the percentage of disability. Mathematical tests for this purpose require considerable concentration and are not very fascinating to the average medical mind. However, if all the factors in the various units as described here are analyzed thoroughly, it is not difficult to establish an evaluation by a simple formula method previously suggested by the author.*

All the disabling factors are related, and there is more or less duplication in the importance of the items of significance in the various units. The method of arriving at a percentage of disability, then, is essentially that of obtaining a percentage average of the importance of the various disabling factors encompassing the case.

The formula is an aid in this process of analysis. It may be stated:

$$\frac{\text{Functional Deficiency} \quad \%}{700} \times .75 + \frac{\text{Physical Impairments} \quad \%}{500} \times .25 = ____\% \text{ Disab.}$$

The functional-deficiency average is found by rating each of the seven functional units and dividing by 700. The physical impairment average is established by rating each of the five factors and dividing by 500. This provides an average for each of the components of disability.

The loss of function is of much more importance in relation to the disability than that of the physical impairments which cause it. Therefore, this component is weighed by 75, with the physical-impairment component a remaining proportion of 25. Consequently, 75 per cent of the average functional loss added to 25 per cent of the average of physical impairment loss will give the rating of disability.

The merit of such a formula is that it forces the examiner more or less to place before him a charting of the various elements of disabling factors under consideration and facilitates arriving at a percentage rating to his satisfaction. If used universally, it would greatly lessen distasteful incidences of unreasonable conclusions in evaluating disability. The formula may be used for an individual unit of the body, such as a finger, an arm or a leg, or for the body as a whole. Suppose the case has been thoroughly examined and the disabling factors are rated in a percentage of loss as follows:

Functional Depreciation. Quickness of action, 20 per cent; co-ordination, 25 per cent; strength, 15 per cent; security or confidence, 10 per cent; endurance, 25 per cent; safety or risk, 15 per cent; prestige of physique, 10 per cent. Total, 120 per cent.

Physical Impairments. Anatomic mass damage, 25 per cent; clinical manifestations, 30 per cent; restrictions of physical requirements, 25 per cent; restrictions of working conditions, 10 per cent; and reactionary interferences, 15 per cent. Total, 105 per cent.

The formula would be applied to these losses as follows:

$$\frac{\text{Function } 120}{700} \times .75 + \frac{\text{Physical Impairments } 105}{500} \times .25 = 17 \text{ per cent disability}$$

Thus, the entire field of disabling factors which are found to affect the body, or part of the body, may be thoroughly analyzed and rated reliably. The following printed form has been devised for office use. Its primary purpose is the filing of a definite record for future reference. It may also prove useful as a part of the report on disability evaluation.

* Instructional Course Lectures, Academy of Orthopedic Surgeons, January, 1955

MEDICAL ANALYSIS OF PERMANENT PARTIAL DISABILITY

Date ____________________

PATIENT'S NAME ____________________ ADDRESS ____________________

CHECK PART OR PARTS OF BODY DISABLED:

Whole Body	Fingers (1 2 3 4)	Thumb	Hand	Arm	Leg	Foot	Toe

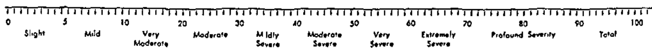
PRESENT STATUS OF INDIVIDUAL

Maximum Improvement reached?	Yes	No
Further Treatment Indicated?	Yes	No

Condition Stationary?	Yes	No
Rehabilitation Indicated?	Yes	No

THE PERCENTAGE RULE OF SEVERITY

Apply this rule to each factor of disability to estimate percent of severity



DISABLING PHYSICAL IMPAIRMENTS

ANATOMICAL AND PHYSIOLOGICAL DAMAGE

(Objective findings only) Check involved factors

Percent less than normal in this case __________ %

BONE DEFORMITY, SPINE DEFORMITIES, JOINT PATHOLOGY, MUSCLE DEFICIENCIES, EYE INJURY, EAR INJURY, SKULL, CHEST, BRAIN CORD NERVES, BLOOD VESSELS, BURSA SYNOVIA, VITAL ORGANS, SYSTEMIC DISEASE, SKIN FASCIA, GENITO-URINARY

REMARKS:

CLINICAL MANIFESTATIONS

Percent less than normal in this case __________ %

PAIN TENDERNESS, MUSCLE SPASM, LOSS OF MOTION, SWELLING INDURATION, INFLAMMATION TEMP, PARALYSIS, REFLEX LOSS, CONTRACTURE, ATROPHY TROPHIC, ISCHEMIA, GANGRENE, LIMP WALKING AID, SYNOVITIS, PSYCHONEUROSIS

REMARKS

RESTRICTIONS ON JOB RESTORATION

(Restrictions of Physical requirements)

Percent less than normal in this case __________ %

LIFTING (Heavy, Light), PULLING, PUSHING, REACHING (overhead), GRIPPING (Finger dexterity, Fist power, Holding), WALKING, RUNNING, LONG STANDING, CRAWLING, KNEELING, STOOPING, BENDING, CLIMBING, THROWING, BALANCING, VISION (Efficiency, Color), HEARING, QUICK THINKING, SPECIAL TALENTS, OTHER FACTORS

REMARKS:

RESTRICTIONS ON WORKING CONDITIONS

(Environmental factors no longer can be tolerated)

Percent less than normal in this case __________ %

OUTSIDE, INSIDE, HOT, COLD, SUDDEN CHANGE, DAMPNESS, DUST, RADIANT ENERGY, ELECTRICAL HAZARDS, GREASE, WATER, SOLVENTS, DARKNESS, SLIPPERY FOOTINGS, MACHINERY HAZARDS, IRREGULAR HOURS, RIDING OR DRIVING STRAIN, OTHER FACTORS

REMARKS:

REACTIONARY INTERFERENCES

(Intangible factors altering future endeavors)

Percent less than normal in this case __________ %

REHABILITATION, LIMITED OPPORTUNITIES, ECONOMIC HANDICAPS, LIMITED EDUCATIONAL BACKGROUND, ADVERSE INCENTIVE TO WORK, ADVERSE SOCIAL RELATIONS, UNFAVORABLE LABOR SITUATIONS, AGE LIMITATIONS, UNPREDICTABLE EXACERBATIONS OF PAIN OR SYMPTOMS, OTHER BODY IMPAIRMENTS OR DISEASE, OTHER FACTORS

REMARKS

Grand total of above five physical impairment units __________ %

Average of physical impairment [ ] %

EVALUATION OF DISABILITY

INTRENSIC FUNCTIONAL DEFICIENCY

Normal value each factor 100%
Compute Loss each Factor

Factor	Loss	Remarks
1 QUICKNESS OF ACTION		
2 COORDINATION, SKILL		
3 STRENGTH		
4 SECURITY, CONFIDENCE		
5 ENDURANCE		
6 SAFETY, UNDUE RISK		
7 PRESTIGE OF PHYSIQUE FOR EMPLOYMENT		
Grand Total Functional Deficiency	Percent	

Average Percent

ELECTIVE FORMULAE FOR RATING DISABILITY

1 Average per cent Physical impairment________ + Average per cent Functional Deficiency________ = ________ per cent Disability

2 Weight by percentage both units according to gravity of disabling influence
Average per cent Physical impairments________ x 25 + Average per cent Functional Deficiency________ x 75 = ________ per cent Disability

3 Whole body disability may be graded:
- Grade I Return to some work 5 to 30 per cent
- Grade II Full work with change of occupation 25 to 40 per cent
- Grade III Indefinite industrial employment 35 to 60 per cent
- Grade IV Employment minimal 60 to 100 per cent

4 Compare gravity of whole body disability to scheduled values for amputation

5 Disability rating for a specified occupation usually is higher than for labor in general

DISABILITY DIRECTED TOWARD

1 ORDINARY MANUAL LABOR	Yes	No
2 SPECIFIED OCCUPATION	Yes	No

IT IS MY OPINION THE DISABILITY FOR________ (PART OF BODY) ________ IS,

	DUE TO INJURY	DUE TO PRE EXISTING INJURY OR DISEASE
PARTIAL TEMPORARY____ Per Cent	____ Per Cent	____ Per Cent
PERMANENT PARTIAL____ Per Cent	____ Per Cent	____ Per Cent

REMARKS

Southwestern Stationery and Bank Supply Publisher
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The above form taken from The Journal of the International College of Surgeons, vol. 24, No 3, September, 1955.

3

Functional and Vocational Recovery in Severe Poliomyelitis*

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During the past decade the medical profession has witnessed and participated in an amazing sequence of changes in relation to poliomyelitis. Notable among these are:

1. An increased number of epidemics with a record incidence of acute cases in the United States
2. A changing pattern of age-group involvement with a shift toward youth and adult groups
3. Greater clinical severity as manifested by increased frequency of bulbar and respiratory involvement
4. A reduction in mortality due to better knowledge and use of mechanical respiratory equipment coupled with tracheotomy
5. An accumulation of severely disabled respirator and postrespirator patients
6. The development of respiratory and rehabilitation centers for their care with resulting improvement in surgical and nonsurgical rehabilitation technics and accomplishments
7. Most important of all, the availability and use of a vaccine promising to eradicate paralytic poliomyelitis in this country

The attitude of the medical profession toward the disease has paralleled and reflected these sequential changes. It has changed from a somewhat hopeless concept when the morality was high to a hopeful one as the rate has dropped. The medical profession has accepted the challenge of the severely disabled convalescent patient and set about finding ways and means to rehabilitate him, both functionally and vocationally.

In order to determine the prognosis of the severely disabled patient we studied and reported* 500 consecutive acute respirator patients with a minimum 2-year follow-up This study included the 2-year mortality rate, the respiratory recovery rate, the incidence of residual respirator patients and the time sequence of such events. The study included patients who became ill between 1950 and 1953, following them into 1955. This time period coincided with the lowered mortality rate and improved convalescent care.

We have continued to follow this group

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† Director of Respiratory and Rehabilitation Center Services, National Foundation for Infantile Paralysis, Inc.

* Affeldt, J E, Bower, A G, Dail, C. W, and Arata, N N.: The prognosis for respiratory recovery in severe poliomyelitis, Arch. Phys Med. & Rehab 38.383, 1957.

of patients in order to extend the observation period and have expanded it to include their functional and vocational recovery.

This paper will present the functional and vocational recovery of the severe poliomyelitic respirator patient over a minimum period of 4 years' observation.

MATERIAL

The 500 poliomyelitic respirator patients reported in the first study* have been used for the continuation study and are the source for the material in this paper. They represent 514 consecutive acute cases admitted to the Los Angeles County Hospital and treated in a respirator between the dates January 1, 1950 and August 14, 1953. Fourteen of the acute cases were omitted because they did not meet the criterion of respirator patients or were lost track of through transfer. All of these 500 patients who survived the acute phase were transferred to a convalescent hospital for further care and rehabilitation, after an average stay of 2 weeks at the Los Angeles County Hospital. Seventy per cent of those transferred came to the Respiratory and Rehabilitation Center for Poliomyelitis at the Rancho Los Amigos Hospital, a County hospital for long-term and chronic disease, where they stayed an average of 9 months as inpatients. This average hospital stay of 9 months represents their initial hospitalization in the convalescent stage. It does not include the acute phase or readmissions for medical complications or further rehabilitation. After discharge some were followed in our outpatient clinic, some through our home care program, some were transferred to other hospitals or outpatient clinics, and some required no follow-up care.

* *Ibid.*

Material for this continuation study was obtained by contact with the patient in the fall and winter of 1957. Such contact was direct, from the medical record, or by questionnaire to his home or other care facility. We were successful in getting information on 418 out of the original 500 patients, which is 83 per cent. This includes knowledge of 79 deaths. We were unable to establish contact with the remaining number, either because of moves with no forwarding address, or no response to our questionnaires.

The material obtained for study included deaths and dates of such, respirator usage with dates for freedom from mechanical aids, residual weakness of arms and legs, ability to help self from a physical standpoint, ability to work or go to school, and vocational status before illness and at present.

The validity of the material is dependent in part upon answers obtained by the questionnaire. However, because the patients were initially all from the local area we have been able to maintain personal or professional contact with many of them, enabling us to know at first hand the answers to many of the questions asked. We have found only a few discrepancies which would indicate ambiguity or misunderstanding of questions asked or bias in the answers one way or another; the number of such would probably not significantly alter our findings.

FINDINGS

The age and the sex distribution are given in Table 1. The present status of the initial

TABLE 1. AGE DISTRIBUTION OF THE 500 PATIENTS AT TIME OF POLIOMYELITIS ONSET AND SEX DISTRIBUTION

Age in years	0-10	11-20	21-30	31-40	41-50	50+	
Number of patients	229	79	126	53	11	2	(500)
Percentage	46	16	25	10.6	2	0.4	(100)
Females	46%						
Males	54%						

TABLE 2. SURVIVAL AND RESPIRATOR USAGE STATUS OF INITIAL 500 RESPIRATOR PATIENTS 4 TO 7 YEARS AFTER ONSET

	No.	Per Cent
Deaths	79	16
Still using *respirator*	*50*	*10*
Completely free of *respirator*	*371*	74
Total	500	100

500 patients as regards survival and respirator usage is shown in Table 2. Seventy-nine patients died, a mortality of 16 per cent. Three hundred seventy-one (74%) became completely free of all respirator equipment. Fifty (10%) were still using respirator equipment 4 years or more after onset of disease. The term "respirator equipment" as used here means any form of mechanical respiration This includes the tank or cuirass respirator, rocking bed, or positive pressure respiration via the mouth or tracheostomy.

The time pattern for deaths is shown in Table 3. In the first year 40 of the 66 deaths occurred during the first month and thus during the acute phase. The low death rate after the acute phase which was seen in the first study* continues beyond the 2-year period. There does not appear to be any significant increase after the first year, indicating that the observed complications continue to take their toll but do not accumulate in such a way as to accelerate the death rate within the time period studied.

* *Ibid.*

Freedom from respirator equipment continues to occur after 2 years, but at a low rate. This is as expected, for respiratory muscle recovery cannot be hoped for this long after onset. The incidence of patients still dependent on resiprator equipment between 4 and 7 years after onset is 10 per cent (Table 4).

The residual involvement of the upper and lower extremities was sought by asking the patient to check one of four categories, (1) none, (2) slight, (3) moderate, (4) severe, for the arms and the legs. We did not try to differentiate between one or both arms or one or both legs or any combination.

The severity checked by the patient does not necessarily correspond with one a therapist or a physician would indicate for that patient during an examination or evaluation, but does reflect the patient's concept of his residual involvement. His concept will of course be influenced by his desires, morale and circumstances, as well as his actual physical status. Eighty per cent of the living patients answered this category with the results in percentage shown in Table 5.

The comparability of involvement between the arms and the legs may appear strange to those seeing mostly patients with lower extremity involvement. However, this

TABLE 3 MORTALITY TIME PATTERN

Years after onset	1	2	3	4	5	6	7
Number of deaths	66	3	4	2	1	1	2

TABLE 4 TIME PATTERN FOR RESPIRATOR FREEDOM

Time from onset									
Months	0-3	3-6	6-9	9-12					
Years					2	3	4	5+	
Number of patients	210	96	26	16	16	3	2	2	(371)
Percentage of total freed	57	26	7	4	4	0 8	0 6	0.6	(100)

Of the original 500 patients, 371 (74%) became completely free of all respiratory equipment.

TABLE 5. DEGREE OF RESIDUAL PHYSICAL DISABILITY 4 TO 7 YEARS AFTER ONSET

DEGREE	ARM(S)	LEG(S)
None	39%	36%
Slight	15%	16%
Moderate	17%	18%
Severe	29%	30%
	100%	100%

group of 500 patients were all respirator patients, who have a high incidence of both upper extremity and lower extremity involvement.

The next area of study was their functional recovery or self-help ability. It was our intent to determine this as simply and grossly as possible, in order to avoid the complex type of analysis involved in detailed activities of daily living. Therefore, we had the patients check one of four questions: (1) completely dependent, (2) partially dependent, (3) no dependence (independent), (4) too young to evaluate. This approach avoids muscle grading, evalution of deformities, motivation, environmental situations, etc. It merely asks whether they can perform their daily functions or do they need the help of others. For example, a severely disabled respirator patient may be fully independent by virtue of a portable respirator, assistive devices to help him with dressing, eating, walking, driving, etc. He may be partially dependent by virtue of requiring someone to help him put the respirator on or help in dressing or some other necessary functional activity. The greatest problem in this approach is that of interpretation by the patient as to his degree of dependence or independence. Of the 421 living patients, 339 (80%) answered the questions of physical dependence or independence. An analysis of the answers to the questions shows that 57 per cent are independent, 27 per cent are partially dependent, and 15 per cent are completely dependent. We did not attempt to place a time factor on the achievement of independent status. Thus one patient may have achieved independence within 1 year whereas another may have required 4 years or more. Our data merely indicates their status between 4 and 7 years after onset of disease.

Their vocational status was approached methodologically in the same way as was their functional status. However, in the vocational category it was necessary to inquire concerning their pre-illness ability. It was also necessary to consider that some are below the age where they must be vocationally independent or that some were below such age before onset but are now in the vocational age group, which we considered to be 16 years or above. We further assumed that if they are still in school, regardless of age, that they are not yet required to be vocationally independent. Their ability to work or go to school was asked by a series of three questions; 337 (80%) of the 421 living answered. Table 6 indicates the present ability to work or go to school as reported by these patients.

Prior to the onset of illness, 142 of this patient-sample were of employable age. Since that time, 25 of those who were previously below employable age or students have entered the employable group. The pre-illness and postillness vocational status is reflected in Table 7. Ninety-six per cent of the currently employable age group answered the questions regarding vocational status These questions determined whether the patient needed financial help or was able to supply his own needs and his family's needs without outside assistance. The pa-

TABLE 6. PRESENT ABILITY TO WORK OR TO GO TO SCHOOL

DEGREE OF DISABILITY	NO	PER CENT
Total Disability	44	13
Part-time activity	67	20
Full-time activity	226	67
	337	100%

TABLE 7. VOCATIONAL STATUS—ADULTS

	Before Illness No.	Before Illness %	Pr[illegible] N[illegible]
Vocationally indep[illegible]	135	95	[illegible]
Vocationally semide[illegible]	7	5	[illegible]
Vocationally depen[illegible]	0	0	[illegible]
	142	100	[illegible]

TABLE 8. LOCUS OF VOCATION

	Before Illness No.	Before Illness %	Prese[illegible] No.
Employed by others outside home	75	22.0	55
Self-employed outside home	10	3.0	8
Employed by others in home	1	0.3	13
Self-employed in home	3	1.0	32
Housewife doing all of work	51	15.0	12
Housewife doing less than half work	—	—	3
Unemployed, but had worked	2	0.7	11
Not employed at present	—	—	167
Below employable age or student	192	58.0	29
Unemployable	—	—	
	334	100	334

tient's previous or present standard of living was ignored in this study.

A more specific analysis of the locus of the pre- and postillness vocational activity is shown in Table 8. Seventy-nine per cent of the 421 living patients answered the questions shown in this table.

DISCUSSION

This group of 500 patients represents a selection of the severest clinical cases of poliomyelitis physicians are apt to see. For with but few exceptions, the fact that dependence on a respirator was the criterion for selection indicates that the patients had a severe life-threatening disease which is usually accompanied by extensive extremity and trunk paralysis. The extent of physical, functional and vocational recovery is greater than we have realized or anticipated, even while working with them or on subsequent contacts. Few would have predicted that only 10 per cent of the surviving group would still be using a respirator. Only a few years ago many felt that the use of a respirator doomed a person to perma[illegible] dependence on it.

Freedom from the respirator de[illegible] imply equal recovery from paralysis [illegible] extremity. Nearly half of the group [illegible] cated moderate or severe residual [illegible] of arms or legs. Despite this high [illegible] of residual involvement, only 15 per cent [illegible] completely dependent upon others for [illegible] in their daily activities, with over half [illegible] completely independent. This degree of [illegible] dependence and function is better shown [illegible] the fact that ⅔ are engaged in [illegible] tivity, be it work or school, with [illegible] per cent engaged part time.

The real test of functional recovery [illegible] be considered synonymous with physical re[illegible] covery, is their ability to earn a li[illegible]. Con- sidering only the adult group, 54 per cent are vocationally independent. This means that they are able to support themselves and, where applicable, their families. Another 18 per cent are semidependent with only 28 per

cent being completely dependent on outside financial assistance.

The good functional recovery shown by this study does not imply recovery from paralysis. These patients have undergone extensive periods of hospitalization for rehabilitation purposes and in many instances are still undergoing such care. The use of physical and occupational therapy to strengthen muscles, prevent or correct deformities, surgery for reconstructive purposes, as well as use of assistive and adaptive devices are important factors in achieving their functional recovery. The patient's motivation is equally important. Their vocational recovery was greatly facilitated by a staff trained to test their potential and then assist them in selecting and obtaining vocational training and eventually employment In some instances this required extensive use of equipment and home or office alterations.

The recovery of these patients was beyond our expectations. The results certainly justify the money and effort expended in the care and rehabilitation of severely involved patients. The results further encourage similar efforts in other severely disabling diseases.

SUMMARY

Significant findings in a 4 to 7 year follow-up of 500 consecutive acute respiratory poliomyelitic patients, whose illness occurred between 1950 and 1953, are reported. Information was obtained concerning 83 per cent of the original patient-sample. Of the original 500 patients, 16 per cent died, 74 per cent became completely free of respiratory equipment and 10 per cent are currently using respiratory equipment either part or full time. Nearly two thirds of the patients have residual paralysis of arms or legs to varying degree. The vocational analysis indicates that slightly over half of the adult part of the sample are vocationally independent with the rest being vocationally dependent or semidependent. Considering the severity of the group of patients studied, both the respiratory and the vocational recovery are far better than one might have predicted or hoped for at the time of their acute phase of poliomyelitis.

Restablimento Functional e Vocational post Sever Poliomyelitis

Summario in Interlingua

Cinque centos patientes consecutive de poliomyelitis acute requirente le uso del respirator esseva tenite sub observation durante al minus quatro annos pro determinar le resultatos final. Occurreva 79 mortes (16%), incluse 66 durante le prime anno Tres centos septanta-un (74%) se emancipava completemente ab omne adjuta respiratori—in le majoritate del casos intra le prime sex menses del morbo. Assi le incidentia residue del uso de respiratores a un epocha de inter quatro e septe annos post le declaration del morbo amonta a 10 pro cento. Quasi duo tertios del patientes ha un paralyse residue de bracio o gamba

In despecto del alte incidentia de paralyse residue del extremitates, 57 pro cento del patientes esseva completemente independente ab le puncto de vista functional, con solmente 15 pro cento completemente dependente de alteros in lor activitates quotidian. Le plus importante criterio del restablimento de patientes adulte es lor capacitate de ganiar lor vita e de supportar se e lor familias. Cinquanta-cinque pro cento del adultos es occupationalmente independente, e 18 pro cento del resto es independente al minus in parte.

Le restablimento de iste patientes con severissime formas del morbo excede per multo nostre expectationes. Le restablimento functional e vocational es in grande mesura le effecto del disponibilitate de extense e active programmas de rehabilitation a un tempore quando le majoritate del patientes es ancora paralysate.

4

Overwork Weakness in Partially Denervated Skeletal Muscle

R. L. BENNETT, M.D., AND G. C. KNOWLTON, PH.D.*

The degree of recovery of muscle strength lost through disuse, disease or trauma depends not only on the site and the extent of irreversible damage to the systems of the body but also on the ability of the patient specifically to contract the involved muscles against increasing resistance. In effect, this means that it takes muscle work to get muscle strength. Because of this, exercise to regain effective muscle strength is a common medical prescription. This prescription may be quite specific and limited to the strengthening of one muscle or a group of muscles, or it may consist of general directions regarding the patient's daily activities at home, in school or on the job. Unfortunately, muscular activity, whether specific or general, may result in loss of muscle strength if the work load is excessive and prolonged. In a Harvey lecture given before the New York Academy of Medicine in February, 1906, Lee[1] pointed out that moderate activity promotes self-preservation, while extreme activity can result in self-destruction. In this paper we are concerned with "self-destruction," but only as it applies to skeletal muscle. We certainly are not attempting to discuss the effects of fatigue on the various systems of the body, nor are we even attempting to discuss the effects of fatigue on skeletal musculature. We are concerned with overwork to specific muscle groups as a result of specific exercises or activities We feel that it is possible by continued voluntary activity to overuse a muscle to a point where long-lasting impairment of that muscle results. In our clinical experience we have seen repeated examples of severe and prolonged loss of muscle strength following specific overuse of the muscle involved. We have caused this deterioration of strength under controlled experimental conditions. We believe that this loss of strength under these conditions may be rightfully thought of as overwork weakness.

Overwork weakness may thus be defined as a prolonged decrease in both the absolute strength and in the endurance of a muscle subsequent to a period or periods of work. To be considered as overwork weakness this impairment must be long lasting as compared with the transient performance decrement normally following any moderately heavy work bout. Overwork weakness is certainly not a new and original finding. Lovett,[4] in his survey of his experience with victims of the 1913 Vermont polio epidemic, repeatedly found that activity caused deterioration rather than the expected and usual improvement in muscle strength. He noted that these occurrences could be correlated with the activity of the individuals; the more active seeming to be more subject to such deterioration. Lundervold and Seyffarth[5] have described the results of voluntary activity upon recovery from experimental pressure paresis and noted that attempts at heavy exercise delayed recovery

* Georgia Warm Springs Foundation, Warm Springs, Ga.

It must be admitted, however, that the question of overwork is controversial. Many highly capable men in the field of medicine and its supporting sciences do not agree that muscle can be overworked through voluntary effort. Therefore, we must attempt to answer the question of why the possibility of overwork is not recognized more generally. Terminology is an immediate stumbling block. There is more agreement in fact than in terminology concerning the overuse of muscle. Most of this disagreement involves the use of the word "fatigue." To some, this is the sensation aroused by repetitive activity. To others, it is the performance decrement occurring during a work bout. Others may use the term "fatigue" as synonymous with exhaustion. The physiologist uses the word "fatigue" as meaning failure of performance in the face of adequate command. Bartley[1] has recently reviewed these semantics. Actually, overwork, as it occurs, has no necessary relationship to any of these connotations of "fatigue." It must be emphasized that exercise carried to a feeling of tiredness has but little relationship to overwork. In fact, the normal individual responding to the disagreeable sensations of fatigue is in little danger of overwork. Thus, much of the apparent disagreement concerning overuse of muscle disappears if one either does not use the word "fatigue" or else defines the meaning intended in a particular use of this term.

As stated previously, the effects of exercise on muscle depend on the intensity and duration of the work performed. The two diametrically opposed effects, performance improvement and performance deterioration, depend on quantitative differences in the intensity and duration of work for a given muscle. Thus, with too little exercise there is deterioration due to disuse. With more exercise there is improvement. But if the work program is increased too much, again there is deterioration. The average individual has no need for a greater performance ability than suffices for his activities of daily living. These requirements are almost always below the top potential of muscle performance; therefore, most of us are working on the disuse side of our muscle-work relationship. In most individuals, any reasonable training program will produce an increase in muscle strength and endurance. This is such a universal finding that there is a tendency to reject automatically the concept that exercise could ever be undesirable. As will be pointed out later, it is quite simple to differentiate between a muscle weak from disuse and a muscle weak from overwork. An exercise program producing rapid improvement in a muscle weak from disuse will obtain no such response and may actually cause further weakness in the muscle weakened by overwork.

Another factor contributing to the lack of acceptance of the possibility of overwork is Sherrington's[9] concept of a fuselike function of the neural synapse and myoneural junction. According to this concept, there is a well-ordered sequence of failure in the neuromuscular pathways. The first point of failure in transmission of impulses to the muscle fiber occurs at the anterior horn cell synapse. This means that the lower motor unit cannot be damaged from overactivity through voluntary efforts because with overactivity the synapse would fail first, and thus the motor unit would be protected from the effects of this overactivity. This concept is almost universally accepted in spite of the fact of evidence to the contrary.

The question that we must answer is this: Does muscle strength during a period of overwork decrease before there is a decrease of impulses to the muscle from the nervous system? If it does, then the bout of overwork is producing its *strength-loss effect* at the muscle, and the synapse is *not giving* complete protection to the muscle. *Mosso*[8] was the first to show that in repetitive voluntary muscular *contraction* the motor nerve impulses to the muscle gradually *increase* as the muscle responses *decrease*. He pointed out that a curve of the nervous effect was a

reverse of the muscle performance. This finding has been confirmed by electromyographic recording of the muscle action potentials during repetitive activity.[2] Furthermore, Merton[7] has recently shown that the strength of contraction on voluntary effort and the strength of contraction on electrical stimulation is the same. This was true whether the comparison was made on a rested muscle or on a muscle tired from repetitive activity. Thus, two separate types of observations show that the acute performance decrement during voluntary activity is the result of failure in muscle contractility rather than of failure in the neural pathway. This negates the concept that a fuselike function of the synapse and/or the myoneural junction prevents the muscle from voluntary overuse. It seems, therefore, that there is no valid theoretic argument against the concept of overwork weakness as we have originally defined it.

The incidence of overwork weakness is difficult to determine. Certainly, abrupt, severe and prolonged loss of strength in muscles obviously overused in known activity is not commonly seen. Such specific and profound weakness would demand changes in the patterns of use of a bodily segment that could be detected rather easily by the trained physician and probably by the patient himself. In a random study, at Warm Springs Foundation, of patients with muscular weakness following nervous system disease or trauma, an incidence of 1.6 per cent of such dramatic loss of strength was found Admittedly, these patients could be reasonably expected to have more than average susceptibility to overwork. However, this figure of incidence must be considered high if we realize that it represents only patients in whom a severe loss of muscle strength occurred in easily tested muscle groups which could be reasonably attributed to known periods of overuse of the involved muscle. In all of these patients disease or trauma had caused severe initial loss of strength in individual muscles, and recovery of at least functional grades of strength had followed long periods of muscle re-education. A few specific instances will illustrate the occurrence of decrease in strength of specific muscles associated with a period of increased muscle activity.

Case 1. A boy had anterior poliomyelitis at the age of 11 years. He was admitted to Georgia Warm Springs Foundation 1 month after the acute onset when he was found to have moderate to severe weakness of the right lower extremity. During the next 6 weeks improvement was such that the child was fitted with a right short leg brace and dismissed to his home with carefully outlined routines which included limitations of his standing and walking activities At this time the right triceps surae was graded poor plus (P+) standing. During the next 6 months the routines were carefully followed at home, and an outpatient visit showed that at 11 months postpolio the individual could come up on right tiptoe 10 times with ease. The right peroneals were now at a good plus (G+) level. The brace was discarded at this time. The next 6 years of the patient's medical history were uneventful. He could walk without a limp and progressed through the years of his rapid adoles- [illegible]

seemed to have become weaker Examination showed that the right triceps surae was now at a poor plus (P+) level and the right peroneal at fair plus (F+) to good minus (G−). He could not come up onto right tiptoe even once and walked with a pronounced limp Questioning revealed that this weakness had become apparent to him only during the last several weeks and seemed to be the culmination of a series of events which had their beginning a year before, when at 18 he had started college, had gone out for freshman football in the fall and for tennis the next spring. His tennis was so good that he decided on intensive training during the summer and took a job as grounds keeper for a tennis court, where, in addition to the work, he had the opportunity to play tennis. Toward the end of the summer he noticed the weakness of the right leg Institution of a more conservative regimen with return to the use of a short leg brace resulted in only mild improvement of the right triceps surae muscle.

Case 2. A boy had anterior poliomyelitis at the age of 6 months During the next 4 years he had physical therapy and surgery so that at

the age of 5 years he had no apparent residual effects of his polio and was completely brace free. He grew to young manhood and started in business with a partner. This business was just well underway when the partner was drafted into the Army, and the patient undertook to keep the business going by himself. This entailed a considerably increased work load. After 6 months he found himself limping, ordered himself a short leg brace from some mail-order firm and tried to continue his work pace. At first he used his brace only intermittently but in 3 years found that he required the brace full time. After a year of this he appeared as an outpatient seeking help. Unfortunately, the long period of 4 years had reduced the muscle strength of the right triceps surae to such an extent that there seemed little left to work with. He was fitted with a somewhat more suitable brace than the mail-order version and has made no significant improvement in the strength of the right triceps surae, which had been functional for a period of 20 years.

Case 3. A housewife had anterior poliomyelitis at age 32. She was admitted to Georgia Warm Springs Foundation 6 months after the acute onset. The arms, the forearms and the hands were of functional strength except for the intrinsic muscles of the right thumb where the opponens pollicis was graded good minus (G−) to good (G). In contrast, the left opponens pollicis was graded good plus (G+) to normal (N). She was an inpatient for 3 months during which time a full course of functional training was completed. At the time of dismissal the right opponens was graded good (G), the left opponens pollicis was graded normal (N). A year later this individual reappeared as an outpatient complaining of weakness of the left hand. During the year she had had a baby and had done all her own housework. Because of the right-hand weakness she had been trained to use her left hand in most of her activities. The left opponens pollicis now had a grade of trace (T) and the right opponens pollicis a grade of poor minus (P−). A rest regimen was prescribed, and examination 6 months later showed the left opponens to be graded fair plus (F+) and the right poor plus (P+). In the following 2 months, still on a conservative regimen, both muscles returned to a grade of good (G).

These 3 examples of the advent of muscle weakness following upon muscle exercise are typical in that they occurred outside the realm of medical supervision and progressed in an insidious manner to a marked weakness before the patient became fully aware of the situation. The next 2 examples are in contrast with those just cited; they will be seen to have occurred under what was thought to be adequate supervision of activity.

Case 4. A young man, aged 16, fractured his cervical spine diving into a shallow pool. Laminectomy at C-5 and C-6 was performed revealing severe damage at this level. Eight months postaccident, he was admitted to Georgia Warm Springs Foundation for rehabilitative procedures. His radial wrist extensors had good strength and control while he had no control of finger flexors. During the first month of his hospitalization at Georgia Warm Springs Foundation he was fitted with hand splints designed to transfer the power from wrist extension to finger flexion. These worked well for about 6 weeks, when the patient complained that the wrist extensors were getting too weak to power finger flexion. Discontinuance of the splints resulted in minimal increase in wrist extensor power but the patient was finally discharged without the splints and with no desire for them.

Case 5. A man had anterior poliomyelitis at the age of 31 years. Two months later he was admitted to Georgia Warm Springs Foundation for treatment. The particular muscle that concerns us here is the right biceps femoris which on admission had a strength grade of poor (P). Under a regimen starting in a conservative manner and progressing to functional training this muscle advanced to a grade of fair plus (F+) in about 5 months. At this time he could lift 40 ounces with this muscle. He was then given a bout of exercise in which he made 26 consecutive lifts of a load of 32 ounces After a 15-minute rest he could not lift 24 ounces but made 25 consecutive attempts at lifting this weight. One week later his maximum load for this muscle was 24 ounces, which he could lift once. After another week his maximum load was still 24 ounces, which he could lift 3 times. Eight months later his maximum lift was 43 ounces, only 3 ounces above what it had been a year before and before the particular exercise bouts mentioned above. This is an instance of an abrupt and long-lasting loss of strength following upon a specific bout of exercise.

What effect overwork had on the failure of other patients to recover at all following

acute illness or trauma is difficult, if not impossible, to say at this time. Since it is not always easy to quantitate precisely the extent of irreversible damage done to the central nervous system by primary disease or trauma, it is easier to excuse our failures on underlying pathology than to accept the possibility that prescribed or permitted activity could be a major factor in the failure of recovery.

The reasons why we would expect a high incidence of overwork weakness in patients with partial denervation of skeletal musculature can be explained best by the very reasons that we would expect a very low incidence of overwork weakness to develop in normal individuals. As previously stated, the average individual has neither the need nor the desire for a greater performance ability than is sufficient for his daily activities. For special athletic performance, or for special jobs, such as combat military duty, individuals are given training programs to increase strength and endurance. The success of these programs indicates that the general population, due to disuse, lacks muscle strength and endurance. Muscular performance that seems astounding might be almost commonplace if the general population were inclined to greater physical effort. The extent of this can be illustrated from the results obtained from a control subject in a training regimen. The training was directed to the wrist extensor group and consisted of daily exercise bouts wherein the trainee made 250 maximal lifts of a load, the weight of which was just over the weight of the optimal load (the load to give maximum work in a single lift). The total work done in the 250 lifts was used as a measure of performance. In the trials of the first week of training the total work for each day averaged 80 kilogram-meters The training period lasted 20 weeks. The average work output per work bout during the final training week was 484 kilogram-meters—a performance improvement of 600 per cent Thus, disuse weakness may be said to be an almost universal condition, and the average individual is far from an overwork level in his usual daily activities.

An important deterrent to overwork is the feeling of tiredness that results from repetitive muscular activity. This sensation seems to result from an interpretive synthesis of a variety of information which includes afferent impulses from the active muscle, associated memory and associated input from the cortical motor areas. These several input sources can have a great number of combinations that can lead to a sensation of tiredness that reaches the threshold of work refusal. For instance, the mere thought of a task can leave some individuals prostrate. On the other hand, the same individual, in a different situation, may carry out repetitive activity to a point of extreme muscle failure without awareness of tiredness.

It is well known that the normal muscle cannot be commanded to expend energy at a rate beyond the capacity of the muscle circulation to provide replacement and remove waste products. The detector mechanisms and the afferent pathways which convey such information concerning these events have not been described precisely but certainly involve pain pathways when a certain depletion level is reached. This information is an important part of the afferent input leading to a feeling of tiredness. At least in part, tiredness must depend on a discrepancy of muscle work capacity and muscle blood supply. One of the chief effects of endurance training is improvement in muscle circulation.[6] The patient with partial denervation of skeletal musculature resulting from a neuromuscular disease, such as poliomyelitis, has an available blood supply to the remaining muscle fibers far greater than existed normally. This would tend to minimize the anoxic complaint of tired muscle and thus tend to limit the protective aspects of disagreeable fatigue sensations.

The total proprioceptive information yield from an active muscle is also important to the feeling of tiredness. In some way this is correlated with the amount of motor activation required to produce the movement. It

was pointed out previously that in repetitive effort there is a gradual increase in the innervation effort required to produce a given response of the muscle. It has been shown that in control subjects there is a definite relationship between the innervation effort and the refusal point for a work load. In general, the refusal point is reached when the innervation effort required is approximately double that needed at the start of the exercise routine. The average individual seems to be conditioned to expect a certain relationship between effort and response. When the innervation effort reaches a certain disparity with the response produced, the individual says that he feels tired.

If the factors enumerated above account for the low incidence of overwork weakness in the average individual, it is not difficult to see that they might well be the very reasons for the high incidence of overwork weakness in individuals susceptible to overwork because of neuromuscular disease or trauma. These factors may be summarized by stating 5 situations that alone or in combination could lead to overwork weakness: (1) when the repeated demands on a muscle equal or exceed the maximum strength and endurance; (2) when the maximum work output of the muscle does not challenge the muscle circulation; (3) when the individual is conditioned to tolerate a high disparity between innervation effort and extent of response; (4) when initial innervation effort is so great that incremental increases are below the least detectable difference; (5) when motivation for performance is so great as to negate the sensation of tiredness. Each one of these situations is far more likely to exist in the individual with a partially denervated muscular system.

This discussion of overwork weakness would be of academic interest only if such weakness could be neither prevented nor favorably treated Fortunately, we have both the means of preventing as well as of treating most instances of overwork weakness

Prevention requires, first, that the physician accept the dangers of overwork and then prescribe exercises or permit activities that can reasonably be expected not to overwork the muscles that must take part. To write such a safe prescription requires the physician to be able to test accurately muscle strength and to anticipate the effect of his prescribed activities on muscles of limited strength and endurance. The trained physician has little difficulty in writing this prescription when dealing with the large muscle groups of the body, as they are, for the most part, easily tested, and their function is well known. Unfortunately, the danger of overwork is greatest in those muscles not easily tested. The intrinsic muscles supporting the vertebral column, so essential to spinal alignment, are excellent examples of muscles that are difficult to test and whose functional anatomy is not completely understood. Recognizing our limited abilities to analyze accurately the strength and the use of these muscles makes it doubly necessary to protect them by proper support and limitation of activity in all positions and movements that might require their use.

One of the greatest dangers of overwork is to those muscles so severely involved by the primary neuromuscular lesion that even the simplest demands on them constitutes the possibility of overwork. We have no evidence that overwork weakness can occur more easily during the recovery phase of a neuromuscular disease, but it might be assumed that the weaker the muscle is the easier it should be to overwork through apparently innocuous activity.

The diagnosis of overwork weakness is not difficult. This weakness is characterized by: (1) decreased strength and endurance that can be reasonably related to specific overuse; (2) failure to regain strength with specific exercise.

Decreased strength in specific muscles can be picked up by repeated muscle testing, but, in most instances, it is first noted by an altered pattern of movement of bodily segments during activity. As the muscle becomes weaker and incapable of performing

adequately in a usual pattern of movement, the patient consciously or unconsciously alters this pattern to continue his activity. Such alterations of patterns should be considered evidences of increasing weakness of muscle groups, and these muscles should be specifically tested for loss of strength. Decreased strength must be reasonably related to specific overwork of muscle groups in known activities. Before the physician can make a diagnosis of weakness due to overwork, he must, of course, rule out the other possible causes of muscle weakness. Loss of muscle strength, seemingly directly related to overwork, could be due to increasing weakness of a progressive neuromuscular disease. This might demand revision of the initial diagnosis or it might indicate that a second disease is complicating the initial problem. In a disease such as poliomyelitis, characterized by isolated and spotty denervation of motor units, it is common to find decreasing strength as the denervated muscle fibers degenerate and are replaced by fatty tissue. This fatty tissue acts as an absorbing material, limiting tension in the muscle when the islands of intact muscle contract. This loss of strength is usually seen between the third and the sixth months following the acute onset of poliomyelitis. Loss of strength in specific muscle groups may also follow lengthening of these muscles by manual stretching or by surgery. Likewise, contractures of muscle or of both muscle and tendon will bring about marked loss of strength through change of the mechanical advantage of the muscle in its normally functioning range. Loss of strength might also be due to increasing weight of the patient. The muscle normally capable of performing useful function may be too weak to continue this function and appear to have lost strength The muscle may actually be as strong as it ever was but, against the increasing weight of the patient, show inability and apparent loss of strength in its functional performance

Most commonly, loss of strength due to overwork may be confused with weakness that results from the opposite problem, disuse. However, this is rather simple to differentiate, because failure to regain strength with specific exercise is an outstanding characteristic of overworked muscle. On the other hand, muscle weakened from disuse will respond favorably to graduated specific exercise by showing increased strength. Certainly this is the simplest way to differentiate between muscle weakness from overwork and muscle weakness from disuse. As stated previously, the muscle that has been overworked and has lost strength will not regain strength, as would be expected of a muscle that has been unused. Exercises can be set up that will specifically determine the ability of a muscle or muscle group to gain strength under increasing work. The muscle that has been overworked should continue to lose strength as further work is demanded. If overwork has caused a decrease of muscle strength, and this decrease is recognized early, resting the muscle should restore all, or part of the previous strength. Rapid loss of strength following a second bout of overwork should then be diagnostic.

If muscle weakness occurs and it is obvious after analysis that this weakness can be attributed to overwork, then certain treatment must be instituted immediately. We have proof that such weakness is reversible, if it is discovered early. Immediate treatment consists of complete rest of the muscle involved. The method by which this rest is obtained must be decided by the physician who analyzes the problem. Rest might require complete rest in bed, or even the application of an immobilizing cast. It might require the use of crutches to protect weight-bearing groups, or other orthetic devices to support and rest the bodily segment involved. As a general rule, the muscles showing overwork weakness should not be used for a period of a week or two, and then gradually started on a muscle re-education program of carefully applied increasing resistance. In effect, the patient is started back

on a program normally instituted in the very early phases of recovery from neuromuscular disease. Then activity is increased as rapidly as recovery of muscle strength indicates its safety. Of course, the degree to which the activity is eventually limited will depend on the importance of the muscle or muscle groups involved. It must be recognized that weakness that follows overwork of muscle may be irreversible. This may be due to the severity and the duration of overwork, or to the inability to protect the muscle groups adequately against further overwork.

Recovery from overwork weakness thus depends on the ability of the physician to recognize the very earliest evidence of overwork and to apply adequate methods of protection of the muscle for its recovery.

SUMMARY

It has been the purpose of the authors in this paper to point out the danger of deterioration of muscle performance following muscular overwork. Five situations have been suggested as predisposing to overwork weakness. It was emphasized that the physician must accept the responsibility of preventing overwork weakness through anticipation of its dangers. If overwork weakness has occurred, recovery of strength will depend on early recognition, the immediate institution of rest, followed by careful muscle re-education and limited activity.

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Debilitate per Excessos de Travalio in Partialmente Disnervate Musculos Skeletic

Summario in Interlingua

Le termino "excesso de travalio" es applicabile quando repetite episodios de exercitio es sequite per un debilitate progressive del musculos participante in le exercitio in loco del effecto de training que es usualmente observate in musculos normal. Cinque situationes que pare resultar—individualmente o in combination—in debilitate per excesso de travalio es le sequente. (1) Quando repetite demandas facite a un musculo equala o excede su fortia e su endurance; (2) quando le rendimento maximal del travalio de un musculo non affice le circulation in le musculo; (3) quando le individuo es conditionate a tolerar un alte disparitate inter effortio de innervation e grado de responsa; (4) quando le effortio de innervation initial es si grande que augmentos additional remane infra le minimo de differentias detegibile; e (5) quando le motivation del effortio es si dominante que le sensation de fatiga es cancellate. Il es le responsabilitate del medico recognoscer le existentia de iste situationes e alora prescriber activitates de exercitio intra le limites del potentialitate muscular. Si debilitate per excesso de travalio ha jam occurrite, le initiation immediate de reposo sequite per un cautissime re-education del musculo e per activitates restringite es indicate.

5

The Use of Stand-up and Step-up Exercises in Rehabilitation*

GERALD G. HIRSCHBERG, M.D.

INTRODUCTION

During an electromyographic study of the lower extremities of hemiplegic patients walking on the level, excessive intensity and duration of muscular activity was found in the uninvolved leg.[12]

This muscular activity was considerably greater than that found in the normal individual during level walking (Fig. 1). It suggested that even the fully rehabilitated hemiplegic patient required more strength in the *uninvolved side than a normal person.* For this reason it was thought advisable to start the rehabilitation of the hemiplegic patient by strengthening his uninvolved side. This seemed to be as justified as the strengthening of the upper extremities of a paraplegic patient, a standard rehabilitation procedure.

After attempts to apply conventional exercises to hemiplegic patients it became clear why such a program had not been conducted before. This type of patient is helpless and unhappy on the exercise mat Dumbbell and pulley exercises with heavy weights cannot be carried out because of difficulty with trunk stabilization in a hemiplegic patient. Chinning and push-ups are impossible with one arm. In effect, the early hemiplegic is more helpless than the early paraplegic and is unable to carry out most of the standard exercises. Furthermore, the hemiplegics belong to an older age group and frequently have additional disability. They are psychologically and physiologically ill-suited for a gymnastic exercise program.

Additional insight concerning this problem was gained by electromyographic tracings of normal individuals during the simple act of standing up from a chair and stepping up a step. The action potentials of the lower extremity muscles were considerably stronger in stepping up and standing up than in level walking (Fig. 2). This fact suggested the possibility of using these maneuvers as exercises for the uninvolved leg of hemiplegic patients

When stair-climbing exercise was first tried out with hemiplegic patients using a flight of regular stairs and banister the response was surprisingly good. Patients who had difficulty standing in parallel bars easily climbed a whole flight of stairs. It became clear that this method of exercise was psychologically more appealing to the elderly, and kinesiologically more suitable for the patient with unilateral involvement than any other standard exercises. Eventually, the method was found to be advantageous for many other disabilities involving lower extremities [14]

While the mechanics of gait in level walking have been studied in detail,[4,5,6,18,20,21,22] many fewer data are available on the mechanics of stand-up and step-up.[3] However, a general idea of the forces involved can be

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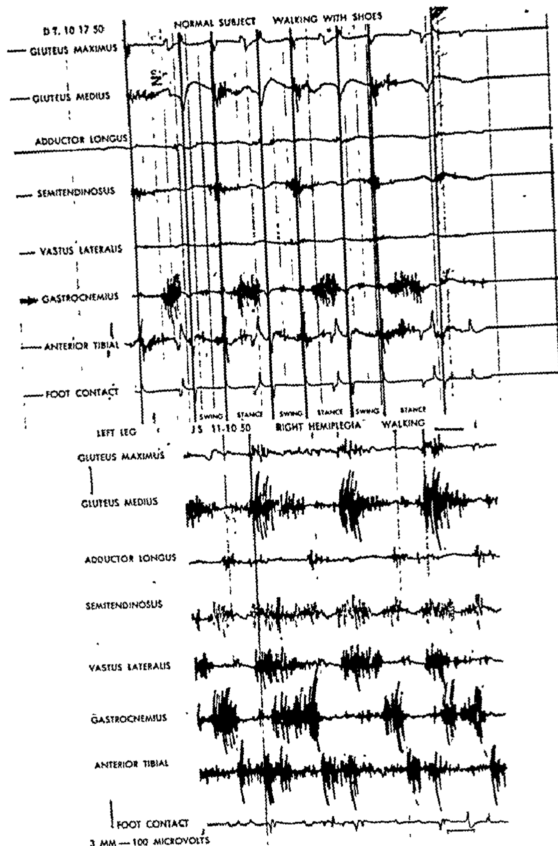


FIG 1. Electromyographic recording of electrical activity in gluteus maximus, gluteus medius, adductor longus, semitendinosus, vastus lateralis, gastrocnemius and anterior tibial on level walking. The tracing at the top of the page is from a normal subject. The one below it is from the uninvolved leg of a hemiplegic. Calibration in both recordings is identical. Note the higher and prolonged electrical activity in the uninvolved limb of the hemiplegic. (Hirschberg and Nathanson: Arch Phys. Med. 33:217-225)

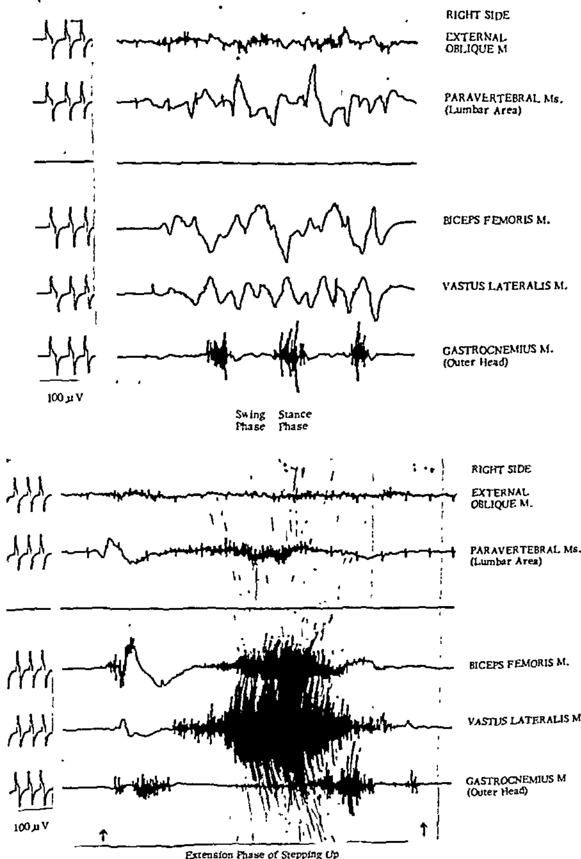


FIG. 2. Electromyogram of external oblique, lumbar paravertebral, biceps femoris, vastus lateralis and gastrocnemius muscles during level walking (*top*), step-up (*bottom*). (*Continued*)

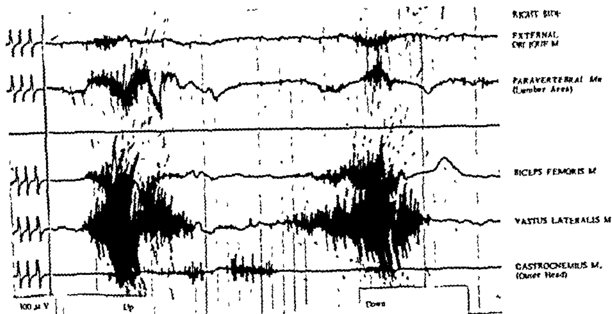


FIG. 2 (*Continued*). Stand-up and sit-down. Calibration identical in all three tracings The irregular waves during level walking are displacement artefacts and do *not* represent action potentials. Note the greatly increased electric activity in all muscles except gastrocnemius during step-up, stand-up and sit-down.

provided by the application of simple mechanical principles.

THE PROGRESSIVE RESISTANCE PRINCIPLE IN STAND-UP AND STEP-UP EXERCISES

Stand-up and step-up exercises are extensor exercises involving the trunk, the hip, the knee and the ankle. If carried out properly, i.e., in a balanced position, they are kinesiologically comparable to knee bends (Fig. 3). The stand-up and step-up phases correspond to the straightening, and the sit-down and step-down phases correspond to the bending of the knee. The only difference between knee bends and step-up or stand-up exercises is a slight forward or backward displacement of the body in the last two.

During a balanced stance with a bent

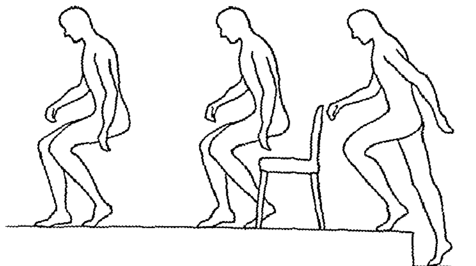


FIG 3 (*Left*) Knee-bend. (*Center*) Stand-up. (*Right*) Step-up.

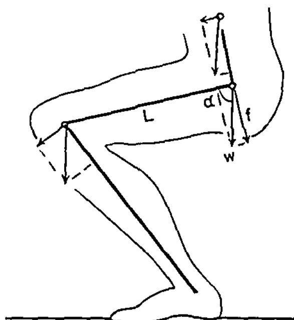


FIG 4. When the lower limb is flexed the patient's weight, w, above a given joint exerts a rotary force on hip, knee and ankle joints. The component f, perpendicular to the lever arm, l, is obtained from the formula f = w sine α. The angle α is formed by the lever arm with the vertical. The rotary force at the joint is expressed by the formula: F = lf or F = l w sine α.

knee, the body weight acts as a rotary force or moment on hip, knee and ankle joints This force is determined by the subject's weight, w, the length, l, of the segment of the limb, and the angle, α, which the segment forms with a vertical line. It is expressed by the equation $F = lw \sin \alpha$ (Fig. 4). The knee moment is maximum when the thigh is horizontal ($\alpha = 90°$, $\sin \alpha = 1$, $F = lw$), and it decreases as the subject straightens up. It becomes zero when the thigh is vertical ($\alpha = 0$, $\sin \alpha = 0, F = 0$). The same applies to the ankle and the hip joints The more bent the subject, the greater are the angles formed by leg, thigh and trunk with the vertical, and the greater is the rotary force at ankle, knee and hip. Therefore, greater effort of the antigravity muscles is required to maintain the position Conversely, the straighter the subject the less muscular force is required to maintain the position, until it becomes zero in the erect position. The fact that very little muscular effort is exerted in the stable erect position has been confirmed by electromyographic studies.[17]

Of the three factors of the equation $F = lw \sin \alpha$, the length of the segment of limb is fixed, but the angle and the weight are variable. A low step or a high chair reduce the angle and give the patient less resistance to initiate the exercise program. By raising the step or lowering the chair the resistance can be gradually increased.

The other variable is the patient's weight. Frequently, it will be desirable to give patients a strict reducing diet before starting the exercises in order to minimize the resistance in the beginning. Later on, the patient's weight can be increased by having him carry a backpack during exercises.

By controlling both factors, the angle at the joints and the patient's weight, a fine gradation of progressive resistance can be carried out.

The sequence of increasing and decreasing resistance and the quantitative range of resistance during a single exercise is of importance. For example, in doing a deep knee bend the resistance against the exercising muscles ranges from zero in the erect posture to maximum in the full knee bend position and then from maximum to zero Reversal occurs at the point of maximum resistance and involves a strain which weak muscles may not tolerate. This excessive strain is avoided in sit-down or step-down exercise. In the sit-down exercise the point of maximum resistance is followed by a support phase on the chair. In the step-down, the force of resistance developed at the time of knee flexion is taken up by the supporting leg.

ENERGY REQUIREMENTS

Information on the energy requirements of stand-up and step-up exercises is rather sketchy. Weiss and Karpovitch[23] studied the energy requirements of many exercises but did not include stand-up and step-up. Physiologic studies of energy expenditure during stair climbing of normal individuals

TABLE 1. ASCENDING STAIRS

AUTHOR	STEP HEIGHT (in.)	VERTICAL SPEED (ft./min.)	BODY WEIGHT (lbs.)	ADDITIONAL WEIGHT (lbs.)	ENERGY (Calories/ min.)
Karrarch	7.9	52.5	—	0	4.6
Benedict	5.1	31.0	127.8	0	4.8
Passmore	—	48.4	130.0	0	6.0
Karrach	17.7	17.8	—	0	6.8
Benedict	8.2	33.0	136.6	0	7.4
Passmore	—	48.4	152.1	0	8.4
Passmore	—	57.4	152.1	0	8.4
Passmore	—	57.4	130.0	0	8.5
Ford and Hellerstein	9.0	10.0	—	5.5	8.5
Gordon	—	27.0	—	17.0	9.0
Passmore	—	48.4	187.3	0	9.3
Passmore	—	48.4	174.1	0	9.7
Passmore	—	57.4	174.1	0	10.4
Passmore	—	57.4	187.3	0	11.8
Karrach	6.7	55.1	156 5	0	15.1
Lehmann	6.7	55.1	combined wt.: 302.6		29.6

have been done by a number of investigators.[2,7,8,9,11,17,19] They are difficult to compare because of the number of variables: step height, speed of vertical rise, body weight and additional load, all of which were not always reported. Table 1 summarizes some of the findings. Energy requirement is expressed in calories per minute.

These findings indicate that energy expenditure increases with the speed of ascent and the total load. Karash actually found that the energy requirement is a linear function of the patient's weight.[16] Compared with other activities of daily living stair climbing at normal speed is very strenuous.

Descending stairs is less strenuous as shown in Table 2.

No studies on stand-up exercises are available, but it can be assumed that, as in the case of stair climbing, it would be quite strenuous if done at a fast rate and that its energy cost is proportional to the body weight.

It should be pointed out that these studies relate to healthy normal subjects. Disability is certain to increase the energy requirement. Studies on step-up or stand-up on disabled persons are not available, but it was shown that ambulation on the level may cost the paraplegic 8 calories as compared to about 2 calories for the normal.[10] Energy requirements of the hemiplegic patient are also higher during activities than those of normal patients.[1]

STAND-UP EXERCISES

DEFINITION

Stand-up exercises are therapeutic exercises which involve standing up from a chair and sitting down by the use of one or both lower extremities.

TABLE 2. DESCENDING STAIRS

AUTHOR	STEP HEIGHT (in.)	VERTICAL SPEED (ft /min.)	BODY WEIGHT (lbs)	ADDITIONAL WEIGHT (lbs.)	ENERGY (Calories/ min.)
Gordon	—	—	—	0	4.3
Benedict	8 2	57.0	143.3	0	5.2

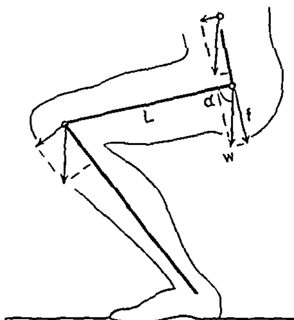


Fig. 4. When the lower limb is flexed the patient's weight, w, above a given joint exerts a rotary force on hip, knee and ankle joints. The component f, perpendicular to the lever arm, l, is obtained from the formula f = w sine α. The angle α is formed by the lever arm with the vertical. The rotary force at the joint is expressed by the formula: F = lf or F = l w sine α.

knee, the body weight acts as a rotary force or moment on hip, knee and ankle joints. This force is determined by the subject's weight, w, the length, l, of the segment of the limb, and the angle, α, which the segment forms with a vertical line. It is expressed by the equation F = lw sine α (Fig. 4). The knee moment is maximum when the thigh is horizontal (α = 90°, sine α = 1, F = lw), and it decreases as the subject straightens up. It becomes zero when the thigh is vertical (α = 0, sine α = 0, F = 0). The same applies to the ankle and the hip joints The more bent the subject, the greater are the angles formed by leg, thigh and trunk with the vertical, and the greater is the rotary force at ankle, knee and hip Therefore, greater effort of the antigravity muscles is required to maintain the position. Conversely, the straighter the subject the less muscular force is required to maintain the position, until it becomes zero in the erect position. The fact that very little muscular effort is exerted in the stable erect position has been confirmed by electromyographic studies.[17]

Of the three factors of the equation F = lw sine α, the length of the segment of limb is fixed, but the angle and the weight are variable. A low step or a high chair reduce the angle and give the patient less resistance to initiate the exercise program. By raising the step or lowering the chair the resistance can be gradually increased.

The other variable is the patient's weight. Frequently, it will be desirable to give patients a strict reducing diet before starting the exercises in order to minimize the resistance in the beginning. Later on, the patient's weight can be increased by having him carry a backpack during exercises.

By controlling both factors, the angle at the joints and the patient's weight, a fine gradation of progressive resistance can be carried out.

The sequence of increasing and decreasing resistance and the quantitative range of resistance during a single exercise is of importance. For example, in doing a deep knee bend the resistance against the exercising muscles ranges from zero in the erect posture to maximum in the full knee bend position and then from maximum to zero. Reversal occurs at the point of maximum resistance and involves a strain which weak muscles may not tolerate. This excessive strain is avoided in sit-down or step-down exercise. In the sit-down exercise the point of maximum resistance is followed by a support phase on the chair. In the step-down, the force of resistance developed at the time of knee flexion is taken up by the supporting leg.

ENERGY REQUIREMENTS

Information on the energy requirements of stand-up and step-up exercises is rather sketchy Weiss and Karpovitch[21] studied the energy requirements of many exercises but did not include stand-up and step-up. Physiologic studies of energy expenditure during stair climbing of normal individuals

TABLE 1. ASCENDING STAIRS

AUTHOR	STEP HEIGHT (in.)	VERTICAL SPEED (ft./min.)	BODY WEIGHT (lbs.)	ADDITIONAL WEIGHT (lbs.)	ENERGY (Calories/ min.)
Karrarch	7.9	52.5	—	0	4.6
Benedict	5.1	31.0	127.8	0	4.8
Passmore	—	48.4	130.0	0	6.0
Karrach	17.7	17.8	—	0	6.8
Benedict	8.2	33.0	136.6	0	7.4
Passmore	—	48.4	152.1	0	8.4
Passmore	—	57.4	152.1	0	8.4
Passmore	—	57.4	130.0	0	8.5
Ford and Hellerstein	9.0	10.0	—	5.5	8.5
Gordon	—	27.0	—	17.0	9.0
Passmore	—	48.4	187.3	0	9.3
Passmore	—	48.4	174.1	0	9.7
Passmore	—	57.4	174.1	0	10.4
Passmore	—	57.4	187.3	0	11.8
Karrach	6.7	55.1	156.5	0	15.1
Lehmann	6.7	55.1	combined wt.: 302.6		29.6

have been done by a number of investigators.[2,7,8,9,11,17,19] They are difficult to compare because of the number of variables: step height, speed of vertical rise, body weight and additional load, all of which were not always reported. Table 1 summarizes some of the findings. Energy requirement is expressed in calories per minute.

These findings indicate that energy expenditure increases with the speed of ascent and the total load. Karash actually found that the energy requirement is a linear function of the patient's weight.[16] Compared with other activities of daily living stair climbing at normal speed is very strenuous.

Descending stairs is less strenuous as shown in Table 2.

No studies on stand-up exercises are available, but it can be assumed that, as in the case of stair climbing, it would be quite strenuous if done at a fast rate and that its energy cost is proportional to the body weight.

It should be pointed out that these studies relate to healthy normal subjects. Disability is certain to increase the energy requirement. Studies on step-up or stand-up on disabled persons are not available, but it was shown that ambulation on the level may cost the paraplegic 8 calories as compared to about 2 calories for the normal.[10] Energy requirements of the hemiplegic patient are also higher during activities than those of normal patients.[1]

STAND-UP EXERCISES

DEFINITION

Stand-up exercises are therapeutic exercises which involve standing up from a chair and sitting down by the use of one or both lower extremities.

TABLE 2. DESCENDING STAIRS

AUTHOR	STEP HEIGHT (in.)	VERTICAL SPEED (ft./min.)	BODY WEIGHT (lbs.)	ADDITIONAL WEIGHT (lbs.)	ENERGY (Calories/ min.)
Gordon	—	—	—	0	4.3
Benedict	8.2	57.0	143.3	0	5.2

Equipment

The equipment needed for stand-up exercises is simple. It consists essentially of two parts: a chair and a stable object which the patient can grasp for support (Fig. 5).

Though stand-up exercises should be carried out by the use of one or both legs and not by pulling with the arm, the patient may be allowed to hold on to a stationary object for safety and balance. This is particularly necessary in patients who stand up by using only one leg. They may use a bed frame or an overbed frame. If these are not available, the back of a heavy chair or a bracket attached to the wall may serve this purpose. In a hospital, group exercises can be done around a parallel bar or a stall bar (Fig. 6).

Method

The main objectives of the stand-up exercises are to strengthen one or both lower extremities and to develop independent stand-



Fig. 5. Equipment for stand-up exercises. The seat is raised by cushions and by placing the chair on blocks The board between bed and patient helps to control foot position



Fig. 6. Stand-up exercises Group therapy for hemiplegic patients. The paralyzed arm is supported by a sling to prevent development of painful shoulder.



Fig. 7. Two-legged stand-up for strengthening hip and knee extensors. The seat is raised by ½-inch plywood boards. Removal of one board at a time permits progressive increase of resistance.

ing balance In order to achieve this the patient must stand up under his own power and maintain his balance by himself from the beginning The therapist, the nurse or other person *administering the exercise* should stand by for safety only. The chair must be high enough so the patient can stand up without great effort. The weaker and the taller the patient, the higher the chair should be (Fig. 7).

The number of sessions varies from 2 to 6 a day. A convenient way to prescribe is to have the patient sit in a chair 3 times a day for meals and do a stand-up session at the beginning and the end of each chair period. Ten stand-ups at the rate of 1 per minute is an average dose. If the chair height has been lowered to normal a backpack may be used to increase the resistance.

The detail of the exercise will depend on the type of disability and the specific objectives of the exercise. The exact method of exercise should be outlined by the physician according to the needs and the tolerance of the patient.

Conditions

For stand-up exercises only one leg is needed. One-legged stand-up exercises may



Fig. 8. Single-step step-up exercise. The step is made of plywood squares and can be increased gradually by increments of ½ inch. Chair back is used for support.

be used for unilateral lower extremity amputees, hemiplegics, unilateral lower-extremity fractures or unilateral joint involvement. The prerequisites for the exercise leg are: (1) sufficient strength of knee and hip extensors to elevate the body from a chair of appropriate height; (2) sufficient stability; (3) sufficient range of motion; (4) freedom from pain of ankle, knee and hip joints; and (5) sufficient co-ordination to stand on one or both legs by grasping the support. An unstable knee may be improved by the use of an ace bandage or a knee cage.

STEP-UP EXERCISES

Definition

Step-up exercises are therapeutic exercises which consist in stepping up or down one or several steps.

Equipment

The equipment may consist of either a single step or a small staircase.

Single Step. For single step step-up exercises, the equipment consists of an exercise step and a support the patient can grasp (Fig. 8). The exercise step may be a footstool, a low bench or a block composed of several boards of a given thickness to achieve an adjustable height.

Small Staircase. For stair climbing exercises, the patient may use either regular stairs or a special exercise staircase. If regular stairs are used there should be a banister at least on one side, preferably on both sides. If a banister is installed especially for stair-climbing exercises it should be long enough to extend beyond the first and the last steps to allow the patient to hold on from the beginning to the end of his trip.

If a special exercise staircase is used, it may be either especially designed and constructed for a patient's use at home or it may be planned for use in a department of physical therapy. Special exercise steps will differ in several features from regular steps and those for training in daily activities (Fig. 9). For gradation and progression of exercises, staircases with several step heights should be available in a rehabilitation department. One set of 2-inch and one set of 4-inch steps is a minimum requirement, and a series of stairs of 2, 3, 4 and 5 inch steps is desirable.

The width of the staircase may vary according to the purpose for which it is used. For bedside and home use a width of 18 to 24 inches may be desirable. This is also good for patients who need to use both hands while climbing stairs. For a rehabilitation department, staircases of 4-foot width are recommended, since these can also serve for elevation training of crutch walkers and provide enough space for use in group therapy.

Method

General Principles. The general principles are the same whether the patient uses the single step or a staircase. The leg which extends to raise the body while ascending or flexes to lower the body while descending is the exercise leg; the other leg is the supporting leg. It is important to make sure that the banister is used for balance only and that the patient does not pull himself up with the

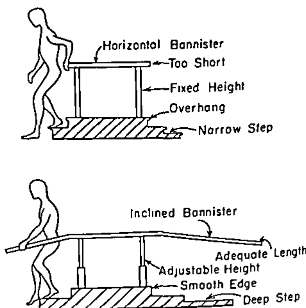


Fig. 9. Comparison of exercise staircase, constructed improperly (*top*) and properly (*bottom*).

TABLE 3. UNILATERAL LEADING METHOD

ASCENDING STAIRS	DESCENDING STAIRS BACKWARD	DESCENDING STAIRS FORWARD
1. Place hand on banister over the center of first step.	1. Place hand on banister at the side of trunk.	1. Place hand on banister over the next lower step and lean forward.
2. Place exercise leg on first step.	2. Step down backward with the supporting leg, descending slowly under control of the exercise leg.	2. Step down with the supporting leg, descending slowly under control of the exercise leg.
3. Elevate body by extension of the exercise leg.	3. Place the exercise leg down adjacent to the supporting leg.	3. Step down with the exercise leg and place it next to the supporting leg.
4. Place the supporting leg on the first step adjacent to the exercise leg.	4. Repeat same procedure for subsequent steps, always leading with the supporting leg.	4. Repeat same procedure for subsequent steps, always leading with the supporting leg.
5. Repeat procedure for subsequent steps, always leading with exercise leg.		

arm, using the lower extremities only as a lever.

If the step-up exercise is used specifically for strengthening of the exercise leg, the elevation should be achieved by the extensor muscles of this leg and not by tiptoeing on the supporting leg.

When using a single step, each step-up must be followed by a step-down which may be either forward or backward. Stair-climbing is less monotonous and allows for more variation of the method. The methods of stair-climbing may vary according to the disability treated and the purpose of the exercise.

Specific Methods

1. ALTERNATING METHOD. In graded exercises the patient usually steps up alternately. This method is also used in co-ordination training and in the last phase of gait training. This technic needs no elaboration. It is the method of ordinary stair-climbing and needs only supervision of posture.

2. UNILATERAL LEADING METHOD. If used as progressive resistance exercises, it is advisable to have the patient step up exclusively with the leg to be strengthened. This is done because the other leg may not need to be exercised, or, if it does, it may need a different resistance (Table 3).

If the patient needs progressive resistive exercises for both lower extremities, this should be carried out separately for each leg. In hemiplegic patients, for instance, the exercise for the uninvolved leg is done during the early phase of rehabilitation, and the exercise for the hemiplegic leg follows later on.

In order to introduce a progressive resistance, the patient may be started on 2-inch steps and gradually progress to regular steps (6½-8 in.). From then on, resistance may be increased by loading the patient with a backpack, the load of which may be increased gradually from 10 to 50 pounds.

In prescribing step-up exercises the physician should specify the purpose (*strength*, co-ordination, range of motion, etc.), the method of lead (alternating or unilateral), the method of descending (backward *or forward*), the step height and the load. In addition, the following data are part of the prescription: (1) number of step-up *sessions*

(1-4 a day); (2) duration of each session (5 min.-½ hr.; rest periods need to be included in longer sessions); (3) climbing speed (60-90 steps per min.; strict observation of climbing speed is important in graded exercises); (4) special precautions should be mentioned according to the need of the individual patient.

CONDITIONS

Before prescribing step-up exercises, one must ascertain that the necessary conditions are fulfilled. The patient needs two legs for this exercise.

The only prerequisite for the supporting leg to permit stair-climbing exercises is a sufficiently great extension of hip and knee to permit support. Pain and muscular weakness need not interfere if the supporting leg is stabilized either by a long leg brace or by a long leg cast.

The exercise leg needs at least "poor" hip flexors to step-up and "fair" or better hip and knee extensors to elevate the body. The knee and the hip must have adequate range of motion, and this activity must not be too painful. Frequently, in arthritic conditions pain may be relieved or attenuated by analgesics and systemic or intra-articular administration of hydrocortisone or similar ster-

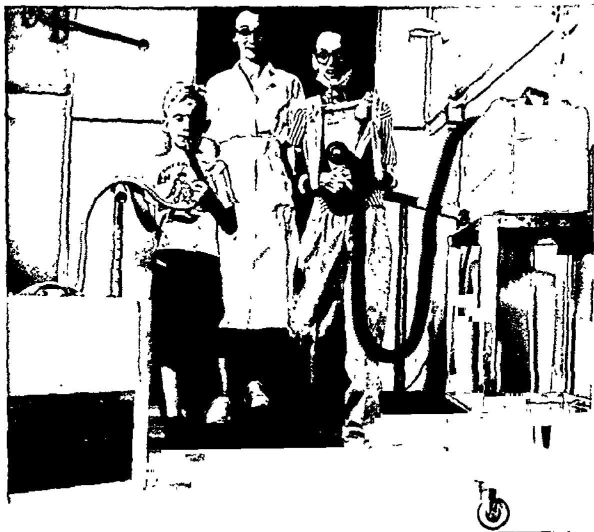


FIG. 10. The boy on the left has only minimal involvement His breathing is assisted by positive pressure The patient on the right has severe paralysis of trunk, neck, upper extremities and respiratory muscles Weak lower extremities are strengthened by descending 2-inch steps Neck brace, body corset and arm slings support paralyzed parts. Cuirass respirator assists with breathing

oids. If the exercised leg is too short or cannot extend sufficiently to permit raising the supporting leg as high as the step, the difficulty can be remedied by a shoe lift on the exercised side.

Neck, trunk, upper extremity and even respiratory paralysis need not interfere with step-up exercises if the patient is properly braced and respired (Fig. 10).

Even if clinical analysis of joints and muscles indicates that the patient meets the requirements for step-up exercises, the patient should first be given a trial before step-up exercises are prescribed.

ADVANTAGES AND GENERAL INDICATIONS

Stand-up and step-up exercises have widespread indications in disabilities of lower extremities. In many instances they are more effective and more economical than conventional exercises.

Advantages. The advantages offered by stand-up and step-up exercises fall into three groups: psychological, kinesiologic and economical.

PSYCHOLOGICAL. From the psychological standpoint perhaps the most important advantage of these exercises is that they are extremely simple and that the activity itself is well known to the patient. This makes it possible to use them in rehabilitation patients who have serious communication difficulties. These are the blind, the deaf, the aphasics and those who speak only a foreign language. Even the patient who is mentally retarded or disoriented because of organic mental disturbances is frequently able to follow such simple orders as "stand up" and "step up." The fact that these exercises are purposeful and present the immediate goal of many disabled patients makes them acceptable to the elderly who often object to a gymnastic type of exercises. Furthermore, there are inherent factors of safety in stand-up and step-up exercises which tend to alleviate the patient's fear of falling He is provided with a stable arm support and since he is standing in front of his chair, the patient can sit down if he tends to tire or lose his balance. Even on stairs the patients show unexpected courage when ascending stairs and are less fearful than when walking on level ground. This may be explained by the fact that the rise of the steps gives the patient the appearance of being less far from the ground (Fig. 11). For the fearful patient it is best to start descent of steps backward, since this prevents him from looking down. The lack of fear is an important factor in these exercises, since they can and should be carried out independently by the patient without assistance. The therapist or person supervising the exercises should stand close enough to prevent falling or injury, but should not assist the patient in efforts of

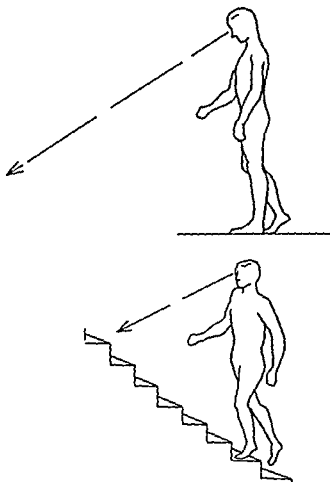


FIG. 11. Rise of stairs gives patient the feeling of being closer to the ground and lessens fear of erect position.

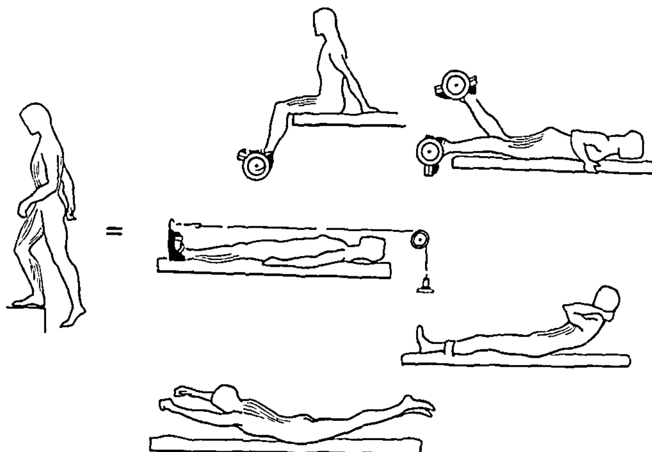


FIG. 12. Step-up exercises combine the strengthening effect of several gymnastic exercises.

elevation or hold him for reassurance. The patient very soon observes that he can carry out the exercises independently and thus gains *confidence in his own ability.*

KINESIOLOGIC. The kinesiologic advantage of stand-up and step-up exercises is that they provide simultaneously the three main objectives of exercises: strength, co-ordination and range of motion. In addition, they allow the patient gradually to become accustomed to weight-bearing, to the *upright position, and to standing balance* They constitute most effective progressive resistance exercises, because the muscular contractions follow a basic reflex pattern of extension and are enhanced by proprioceptive facilitation. In fact, in patients with upper motor neuron lesions a considerably greater extensor response can be elicited by weight-bearing than by voluntary contraction.

ECONOMIC The economic advantage of stand-up and step-up exercises is obvious. The equipment involved is generally available or can be easily constructed. The exercises can be supervised by nonprofessional *personnel or by members of the* patient's family and eventually can be carried out without supervision. Because of the simultaneous strengthening of many muscle groups, the total exercise time is shortened considerably. Figure 12 demonstrates the strengthening value of a step-up without considering its value for co-ordination, range *of motion, weight-bearing,* etc. Since the exercises are simple, safe and must be carried out independently, they lend themselves readily to group therapy *in institutions.* This also contributes to economy as well as efficiency.

Indications. Stand-up and step-up exercises are indicated in three groups of patients: (1) nonambulatory patients as a maintenance program; (2) preambulatory patients as preparation for ambulation; (3)

ambulatory patients for improving of lower extremity function.

1. Maintenance of Strength and Range of Motion in the Lower Extremities. This is indicated in nonambulatory patients who are temporarily disabled by chronic disease, orthopaedic or neurologic conditions. Frequently, the only activity prescribed for these patients is to be up in a chair or a wheel chair. While this is preferable to complete bed rest if carried out properly, the chair period contributes little to the maintenance of the patient's strength, particularly in the lower extremities. If the patient stays too long in the chair, he may develop hip and knee flexion contractures. If, however, each chair period, which should never exceed 1 hour, is accompanied by two 10-minute periods of stand-up and step-up exercises, maintenance of strength and range of motion can be assured.

2. Preparation for Ambulation. Normal ambulation requires strength and co-ordination in trunk and lower extremities. These can be developed conveniently by stand-up and step-up exercises. Ambulation training is commonly initiated by hoisting a patient to his feet and having him stand and walk in parallel bars or a walker or even by being held up by two attendants. Some patients actually become ambulatory despite this rather crude approach. If a patient is too weak to stand up he is also too weak to walk properly. Eventually, he will improve his strength and co-ordination with parallel bar exercise, but only if he bends his knee as he walks and thus practices knee-bend exercises to a minor extent. Frequently, elderly patients and patients with neurologic disability never become ambulatory despite months of "gait training." If the gait training is initiated with stand-up exercises at the bedside, a prognosis can be established rapidly If the patient is unable to stand up, even from a high chair, he will be unable to ambulate safely. However, if the patient is able to stand up and progresses from a higher chair to a low chair, he will be able to proceed to step-up and stair-climbing exercises and walk securely within a relatively short time. Preparation for ambulation is the most important indication for stand-up and step-up exercises.

More specifically, these exercises are indicated in many disorders of the nervous system and the musculoskeletal system. Among the patients with upper motor neuron lesions, the hemiplegics constitute the largest group that has benefited from stand-up and step-up exercises.[13] Because most hemiplegic patients are elderly and may have associated organic mental syndromes, these exercises are often the only ones that the patient can perform. One-legged stand-up exercises for the uninvolved leg may be started while the hemiplegic leg is still flaccid and functionless. These exercises may be used in preparation for ambulation in lower motor neuron disease such as poliomyelitis, Guillain Barré syndrome, peripheral neuropathies, peripheral nerve injuries and in cerebellar or posterior column disease.

Among the musculoskeletal disorders, rheumatoid arthritis, osteoarthritis, fractures of the lower extremities and postsurgical disabilities of knee, hip and ankle may be indications for stand-up and step-up exercises. One-legged stand-up exercises for the uninvolved leg are particularly valuable in the hip-fracture patient.

3. Use in Ambulatory Patients. Stand-up exercises are indicated essentially in those situations in which a patient has difficulty in getting up from a chair of normal height. Improvement may be achieved by stand-up exercises from an elevated chair which is gradually lowered as the patient's strength and skill increases.

Step-up exercises, preferably in the form of stair-climbing, with or without backpack, may be used for improvement of strength and co-ordination of the lower extremities. They can also be valuable in restoration of range of motion in a single joint (Fig. 13). Descending stairs, in particular, is helpful in

extension contractures by increasing the range of flexion of hip, knee and ankle. On the other hand, by strengthening the extensor muscles, stand-up and step-up exercises are also helpful in reducing flexion contractures of hip and knee.

As a graded exercise, stair-climbing is useful in cardiovascular rehabilitation by increasing the tolerance to angina and intermittent claudication. It also provides a means to achieve gradual increase in exercise tolerance of patients recovering from cardiac decompensation and tuberculosis. At the other end of the scale, stair-climbing with a heavy backpack may be used as a strenuous exercise to assist in weight reduction.

Contraindications. There are very few contraindications to stand-up and step-up exercises. Occasionally, local conditions such as infections of the lower extremities or local conditions of bone or joints contraindicating weight-bearing or joint motion may prevent performance of these exercises. Two major contraindications are myocardial infarction and cardiac decompensation. In both instances, a certain amount of exercise may be resumed after the acute phase. Patients with auricular fibrillation should be digitalized prior to stand-up or step-up exer-



FIG 13. Increase of range of motion by step-up exercises Patient E. S., 47 year-old female. Fracture of right patella on June 25, 1957 In long leg cast until August 2, 1957, then physical therapy for 10 days with instruction in home exercises and resumption of normal activity. Started on single-step step-up and step-down exercises and stair climbing on September 19, 1957 No passive stretch was used Knee bends added on October 25, 1957. Range of knee flexion increased from 30° to 100°. Maximum passive knee flexion on September 19, 1957 (*Continued*)

cises to prevent decompensation. A few patients with chronic decompensation may not be allowed to exercise at all.

SUMMARY

Stand-up and step-up exercises are valuable for strengthening of trunk and lower extremities, improvement of lower extremity co-ordination and range of motion, for gait training and for graded exercises in cardiac or respiratory disabilities. The advantages of these exercises as compared with standard exercises are: (1) greater effectiveness; (2) easier availability; (3) greater economy in personnel and equipment; (4) applicability to patients who are not able to carry out standard exercise programs because of mental and psychological limitations.

The technic, the prerequisites and the indications of step-up and stand-up exercises are described.

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FIG. 13 (*Continued*). Maximum passive knee flexion on January 20, 1958.

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Levar Se (Ab Un Sede) e Montar (Un Grado) como Exercitio de Rehabilitation

Summario in Interlingua

Le *exercitios del levar se (ab un sede) e del montar (un grado)* es de valor in le melioration del fortia, coordination, e extension de motilitate in le trunco e le extremitates inferior, in le trainamento del ambulatura, e —in forma progressive—in le domination de *invaliditates cardiac e respiratori.* Le resistentia contra le musculos extensori del trunco e del extremitates inferior pote esser augmentate per reducer le altor del sede in le exercitio del levar se, per adder al altor del grado in le exercitio del montar, e per facer le patiente portar un pacco (super su dorso) in ambe typos de exercitio Le costo total de energia requirite per iste exercitios pote esser augmentate in le mesme maniera. Le avantage de iste exercitios, in comparation con le exercitios standard, es lor plus grande efficacia, lor plus facile disponibilitate, e lor economia quanto a personal e equipamento. Lor valor principal consiste *in lor applicabilitate* a patientes qui non es capace a executar programmas de exercitios standard a causa de limitationes mental o psychologic o a causa de sever grados de invaliditate physic

Le technica, le prerequisitos, e le indicationes del exercitios de levar se e de montar es describite.

6

The Diagnostic Advantages of Electromyography in Neck and Shoulder Disorders

CHARLES A. FUREY, M.D.*

Electromyography deals essentially with recording and measuring the electrical currents generated by normal and abnormal muscles. Proper use of the electrodiagnostic instrument (the electromyograph), together with correct interpretation of the recorded findings (the electromyogram), aids the physician in assessing the functional integrity of the neuromuscular system. When interpreted in conjunction with the clinical findings, electromyography assists in the diagnosis, the prognosis and the treatment of neuromuscular disorders.

HISTORIC BACKGROUND

Clinical electromyography is established today as a diagnostic procedure in neuromuscular disorders. Pioneered by Denny-Brown and others in the 1930's[7,13,21,22] it proved of distinct value to the Armed Forces of the United States and Canada in the early 1940's[4,5,8,12,16,18,29,30,31,32,33,34] and has been perfected in the decade since World War II.[1,2,6,9,10,11,14,15,17,19,20,23,24,26,27,35] The rapid progress in this field has been achieved as a result of research in electronics, including the perfection of the unipolar needle electrode, as well as from increased knowledge of the physiology of the motor units, together with the clinical application of these principles as applied to man.

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INSTRUMENTS AND TECHNIC

The electromyograph is a compact unit. The apparatus consists essentially of an intake cable to transmit action potentials from a needle electrode that has been introduced into skeletal muscle. The cable is attached to a pre-amplification system, a sound amplifier, a loud speaker and a cathode-ray oscilloscope. A tape recorder and a synchronized camera complete the unit.

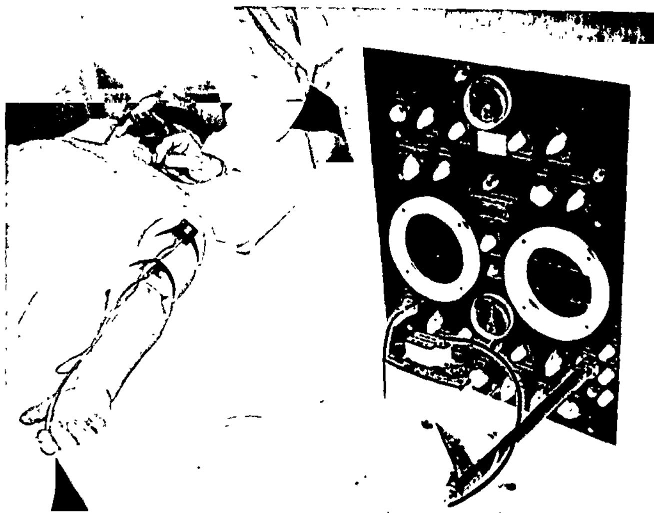
In this manner, the electrical activity of normal and abnormal units can be seen, heard, recorded and photographed.

It is frequently advisable to shield the room being utilized for electromyography with copper wire screening. This prevents outside electrical interference from distorting the characteristic sounds and wave forms on the cathode-ray oscilloscope.

CLINICAL APPLICATIONS OF ELECTROMYOGRAPHY

NECK AND SHOULDER DISORDERS

The contributions of electromyography in general, as an aid to neurologic diagnosis, have been thoroughly covered in the medical literature.[1,2,4-24,26,27,29-35] We have found the electromyograph of particular assistance in neck and shoulder disorders. This area of the body is a source of frequent complaint by the patient and is often perplexing diagnostically to the physician.



Electromyograph with cathode ray oscilloscope, amplifier, loud speaker and camera. Needle-electrode inserted in muscle being tested. Copper-screening shield throughout test chamber.

A concept of the confused nomenclature prevailing in neck and shoulder disorders is grasped when it is recalled that certain of these conditions have been given as many as 12 different names.

As regards the neck-shoulder area, the electromyograph assists in differentiating primary disorders, such as bursitis, tendonitis and the like, from other conditions, in which the symptoms are referred to the shoulder but the nerve-compression cause is elsewhere. The differentiation here is accomplished by demonstrating the presence of characteristic action potentials of a pathologic nature, the presence of which conclusively points to an injured nerve. Furthermore, the location of the lesion and the degree of impairment is likewise demonstrated

The increased knowledge in differential diagnosis of shoulder disorders attained by the use of the electromyograph results in a reduction in the empiric use of therapeutic irradiation to the shoulder. This effective agent can then be reserved for cases that will derive greatest benefit therefrom. Improved operative results in surgical procedures about the shoulder are likewise anticipated, since the electromyogram enables the physician to make a more accurate selection of cases for operation

The electromyograph assists in establishing the diagnosis in those shoulder-neck cases where the history is obscure, the physical findings meager, the roentgenograms negative, and the laboratory work normal. The following case history concerns a man

with shoulder weakness, in whom a definite diagnosis could not be established by the classic procedures.

Case I. W. M., a 41-year-old male, employed as an office clerk, complained of difficulty in lifting the telephone receiver with his left hand. This complaint was of several years' duration. The only other symptom was an uncomfortable click in the left shoulder that occurred occasionally. His job required frequent use of the telephone. As a result of his complaints, this man found it more comfortable to pick up the telephone receiver with his right hand, balance the receiver upon his right shoulder, and then return his hand to the desk to write out the messages incident to the telephone call. There were no other complaints.

The past history revealed an old injury to the left shoulder 12 years before.

Physical findings were negative, except for motor function at the left shoulder. The motor-function test revealed mild weakness in abduction of the left arm at the shoulder, graded as G minus. There was also weakness in external rotation of the left arm at the shoulder, graded at G. Roentgenograms of the shoulder, with the arm in various positions, and numerous special films were negative. An electromyogram was carried out and revealed denervation fibrillation positive sharp waves in 20 per cent of the areas sampled in the anterior deltoid, in 20 per cent of the middle deltoid fibers and in 30 per cent of the posterior fibers. Furthermore, there were positive findings in the upper teres muscle.

A diagnosis of compression of the left circumflex nerve, secondary to the shoulder injury of 12 years before, was established. The patient was placed under treatment, and in 4 weeks the motor function of the left arm abductor and external rotators were equal to or greater than that of the uninvolved arm. The man experienced no further clicking in the shoulder and encountered no further difficulty in lifting the telephone receiver or other objects with his left hand in the normal manner Two years later, this man continues to be symptom-free

Nerve Compression Injuries Due to Trauma

The electromyograph confirms the diagnosis in nerve compression injuries resulting from athletic competition. For example, athletes engaged in football training frequently incur shoulder-neck injuries with associated nerve involvement. The usual complaint is one of weakness, numbness and tingling of the shoulder-neck region of one side and possibly of one arm. These complaints generally first occurred during or shortly after a practice session, in which the candidate was occupied in fiercely charging a blocking apparatus, while running at top speed. His padded shoulder came into forceful contact with the steel blocking apparatus. It is not unusual for several members of a squad to be ineffective at the same time because of this condition. Injuries of this type produce physiologic interruption of one or more nerves and occasionally cause avulsion of the entire plexus. For example, the brachial plexus may be affected. At other times, the long thoracic nerve may be injured. In the latter instance, pressure of the sharp-cornered object upon the shoulder causes compression of the long thoracic nerve with paralysis or paresis of the serratus magnus and results in winging of the involved scapula, together with a surprising amount of difficulty in moving the arm and the shoulder.

In the past, it has been difficult to establish clinically the nerve or nerve groups responsible for weakness and other symptoms in this type of athletic injury. Today, the electromyograph helps to clarify the picture and leads to more accurate diagnosis by pinpointing the involved nerves.

In nerve compression syndromes, it has been our experience that when the electromyogram is preceded by a muscle-function test, time is saved. The muscle-function test serves as a guide, indicating the more severely involved areas, which can then be examined with the electromyograph.

Cervical Root Syndrome

The cervical root syndrome has been discussed frequently in recent medical literature.[3,25] It has been described as probably the most common cause of pain in the upper extremity, the head and the neck.[25] The term "cervical root syndrome," or one of its num-

erous synonyms, refers to a mechanical abnormality producing pain, numbness or tingling, by pressure on one or more cervical nerve roots or portions thereof. In cases of this kind, the electromyogram confirms the presence of nerve involvement and demonstrates the particular nerve root involved. Thus, by more accurately localizing the source of the pathology, the electromyogram reduces the number of etiologic factors being considered.

Cervical Disk Disease

Cervical disk disease is one cause of cervical nerve root involvement and may cause symptoms referable to the shoulder-neck region. In such cases the electromyogram determines not only the presence of a lesion but also its exact location. Here, the single nerve root lesion is localized by demonstrating denervation fibrillation action potentials in the myotome having common innervation from a single nerve root, with the absence of fibrillation from the adjacent myotomes.

Scalenus Anticus Syndrome

The scalenus anticus syndrome is the most common condition involving the brachial plexus. The electromyogram assists in differentiating this syndrome from other lesions commonly affecting the same area A comprehensive report in the recent literature covers the subject.[25]

Cervical Arthropathy

The electromyogram is helpful in establishing a diagnosis of cervical arthropathy in the early stages, when this condition is difficult to establish roentgenologically. At this stage of the disease, the patient complains of stiffness, aches and pains in the neck and the shoulder and occasionally in the arm and the hand. Routine roentgenograms of the cervical neck region are frequently normal. However, the electromyogram points clearly to a unilateral nerve-root involvement and confirms the clinical impression of organic pathology. Repeat roentgenograms at a later date will reveal impingement upon the nerve root in the intervertebral foramen. Hence, in this condition, the electromyogram assists in establishing an early diagnosis.

Exposure to High-Voltage Current

This has a destructive effect on nerve cells. In these cases, when an arm and a shoulder are involved, frequently one leg will be affected also. Muscle atrophy may be extensive. The electromyogram reveals characteristic patterns and assists the physician by recording the profound destruction of the motor units. It also aids in rendering a prognosis for ultimate recovery. If, for example, the electromyogram repeatedly reveals the presence of complete denervation fibrillation, and on attempted voluntary effort, no motor unit voltages appear within the proper period, it can be stated that the muscle is completely denervated, and no recovery can be expected. Thus, the electromyogram reveals important diagnostic and prognostic information.

High Cervical Lesions

One region of the body presenting many problems clinically and roentgenologically is the upper cervical region of the neck. It is in this area, too, that diagnostic error is fraught with grave consequence, for neurologic sequelae and traumatic arthritis are well recognized disabling complications The electromyogram is a valuable procedure from the diagnostic and prognostic standpoint in traumatic lesions of the high cervicals

The following case history will illustrate this point.

Case 2. V. B., a 45-year-old male, complained of pain and stiffness in the back of the neck, over the occiput and between the shoulder blades. He further complained of an area of numbness in the suboccipital region of the neck on the left side. These symptoms were present since an injury sustained while diving in the ocean 3 weeks before At the time of the injury, the patient was stunned but not unconscious While hospitalized, multiple roentgenologic studies were carried out and reported negative.

Three weeks later, an electromyogram was carried out. At this time, the patient continued to have neck and shoulder complaints, including the presence of numbness and abnormal skin sensitivity behind the neck. The following physical findings were present: the head was abducted slightly to the right of the mid-line, the left sternocleidomastoid muscle was prominent, the chin was tilted to the patient's left, and there were areas of hypesthesia, hyperesthesia, hypalgesia and hyperalgesia in the suboccipital triangle. There was also a small area of purplish discoloration below the hairline.

The electromyogram revealed denervation fibrillation present in 40 per cent of the areas sampled in the left rectus capitis muscle and in 40 per cent of the left erector spinae cervices. Upon voluntary effort, complex motor unit voltages were in evidence. Findings were consistent with compression of the nerve roots on the left side of the neck at the C-1, C-2 level.

Following the positive electromyographic findings, roentgenograms were repeated with special views requested of the high cervical region. The roentgenograms revealed the presence of a rotary subluxation of the first cervical with regard to the second cervical vertebra and involving the left apophyseal joint. There was no evidence of fracture. This report confirmed the diagnosis.

This, then, is a case of a high cervical lesion in which the history and the physical findings strongly suggested the presence of either fracture, dislocation or subluxation, but the initial roentgenograms were reported to be negative. The electromyogram revealed unmistakable evidence of nerve compression arising at a definite location, and a diagnosis of nerve compression, secondary to subluxation, was established on this basis.

SUMMARY

Electromyography has made rapid strides in the past 2 decades. It is a useful laboratory procedure in which the findings must be correlated with the clinical picture. Properly interpreted, electromyography is a distinct aid in the diagnosis, the prognosis and the treatment of certain diseases.

The electromyogram is particularly useful in differentiating various conditions having symptoms referable to the neck and the shoulder, as, for example, in differentiating the more frequently occurring shoulder lesions, bursitis, tendonitis, fibrositis and the like from the less common axillary nerve or cervical nerve root pathology. Among the other neck and shoulder conditions in which the electromyogram has been of particular benefit are cervical disks, cervical spondylosis, whip-cord injuries, apophysitis, scalenus anticus syndrome and nerve compression phenomenon. In certain of these disorders, the electromyogram will definitely locate the site of nerve damage, estimate the amount of damage and assist in determining an accurate prognosis.

In conclusion, it may be stated that the electromyogram is to the neuromuscular system, what the roentgenogram is to the osseous system.

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Le Avantages Diagnostic de Electromyographia in Disordines del Collo e del Spatula

Summario in Interlingua

Constatationes electromyographic, correlationate con le tableau clinic, es de adjuta in establir le diagnose. Electromyographia es un technica electrodiagnostic que permitte al medico differentiar prestemente le lesiones spatular de occurrentia plus frequente — i.e. bursitis, tendonitis, fibrositis, etc. — ab le minus commun gravamines

spatular que es associate con affectiones del plexo brachial, del nervo axillar, o del radices de nervo cervical.

Inter le altere disordines de collo e spatula in que electromyogrammas ha essite de utilitate particular, on debe mentionar disturbation del discos cervical, spondylosis cervical, vulneres a "filo de flagello," apophysitis, syndrome de scaleno antic, phenomeno de compression nervose, etc. In certes de iste disordines — per exemplo un invaliditate spatular causate per affection del nervo axillar—il non es possibile establir le diagnose definitemente per medio del manovras routinari, incluse le uso de roentgenogrammas. Le electromyogramma, del altere latere, establi nettemente le sito del lesion nervose, evaluta le grado de su severitate, e contribue al determination de un exacte prognose.

Le electromyogramma es pro le systema neuromuscular lo que le roentgenogramma es pro le systema ossee.

7

The Management of Early Rheumatoid Arthritis by Physical Means

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Increasing interest by a widening number of doctors in the early manifestations of rheumatoid arthritis has led to earlier diagnosis of the disease and thereby to better management of rheumatoid patients. With better understanding of the disease process, physicians have replaced the unrealistic word "cure" with the more practical term "management." And since a major objective in the management of early stages of arthritis is prevention of joint deformity, the technics of physical medicine applicable at this stage of the disease warrant special discussion and emphasis.

The clinical picture of rheumatoid arthritis as presently seen in practice has been changed markedly from that seen a mere 15 years ago by the introduction of two major factors—earlier diagnosis and the use of potent antirheumatic drugs. This has necessitated a thorough reappraisal of the various methods of treatment available. The very chronicity of the disease and its obdurate resistance to even the most widely acclaimed new drugs has again brought to the fore the necessity for the utilization of physical means in both prophylaxis and management. An earlier emphasis on the values of spa treatment, indeed of most forms of hydrotherapy, has been abandoned in favor of less glamorous but more rewarding programs of therapeutic exercise. Methods of preliminary heating are now being used primarily as means of preparing the joints and the musculature for the increasing demands of active, active assistive and resistive exercises. With the widespread use of increasingly potent antirheumatic drugs there is less and less necessity for the casts used in earlier days to reduce pain in the acute phase of the disease.

Clinical effort is focused at present on the early detection of the disease, preferably in the first or the second episode, and consequently on the early training of the patient in the assumption of a more active role in the management of "his own disease." Patients are instructed in the advantages and the procedures of an exercise program conducted consistently at home with frequent recheck examinations to make sure that the patient understands the significance of his own role in the management of this potentially disabling disease. It is not wise to permit more than 2 months to elapse between visits to the physician, as we have found that interest in home treatment programs wanes rapidly after this interval.[7] Patients are taught the dangers that attend their assump-

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tion of "positions of ease" and are especially warned of the deformities that result from malpositions about the wrists, the hands, the knees and the feet. Instructions are written as well as oral.

PRELIMINARY HEATING

In the past there has been a rather regrettable insistence by certain physicians on the clinical merits of individual forms of heat. Such discernible waves of enthusiasm, as for the especial efficacy of short-wave diathermy in the 1930's and at present for the eclectic merits of ultrasound, should be viewed as mere historic incidents in the development of the current healthy skepticism. Such preferences for particular forms of heat are largely the result of a regrettable empiricism, which has both delayed and discredited the proper employment of useful physical measures in the management of this disease. Many well-trained clinicians have been so repelled by the unsupported claims of the advocates of radioactive spas and by the heedless enthusiasm for home-installed bubble baths that they have been unwilling to investigate and to utilize other forms of physical therapy. In the absence of an effective yardstick for assessing objective clinical response to any form of heat, it behooves the physician to consider heat, however applied, merely as an adjunct in the over-all management of the patient with rheumatoid arthritis.

It appears to us that the main uses of heat in the treatment of a chronic musculoskeletal disease such as rheumatoid arthritis can be summarized as follows:

HEAT AS AN ANALGESIC AGENT

All too frequently in earlier texts there is reference made to the employment of heat as a form of analgesia. Very little scientific work has been done to validate the assumption that heat influences either the end organ's response to pain or the conductivity of pain-carrying axons. A study of conduction block produced in the axons of the sciatic nerve of a bullfrog by heat has suggested that blocking of the motor axons (the A fibers) would occur at a lower temperature than would blocking of the pain-carrying axons of the C fiber group.[10] No objective reports have yet been made on modification of end-organ responses by local heating or on possible alterations in pain thresholds during application of heat. However, despite the lack of scientific evidence of its efficacy, heat is commonly used for its muscle relaxing, vasodilating and analgesic effects. Anyone who has lain under an infrared lamp or hot moist pack knows that heat is effective in producing relaxation of tense muscles and seemingly in reducing the amount of pain present. For this reason the use of heat prior to therapeutic exercise is advocated. Sources of local and general heating in the management of rheumatoid arthritis have been discussed previously elsewhere.[8]

HEAT AS A FORM OF MILD FEVER THERAPY

There is clinical evidence that the course of rheumatoid arthritis was influenced at least temporarily by the prolonged fevers used in the late 1930's and early 1940's. The significant changes in the hemogram observed by Krusen and his fellow workers[6] would appear to have some correlation with the increased adrenocortical hormone output that results from stress. Later work by Hubler and others[4] suggests that a standardized stress situation, such as the induction of controlled fever in rats, can induce a drop in the circulating eosinophils. Inferentially, it must be assumed that fever therapy of even short duration, such as is practiced currently in certain centers in the treatment of rheumatoid arthritis, may have a similar influence on the output of adrenal hormones. For the production of such mild fevers a variety of means are available; in one of the more frequently employed procedures the patient is immersed in a Hubbard Tank until the oral temperature is in the range of 99.5° to 101°F. A fever cabinet or moist air cabinet can also be used for 30 minutes. Less



FIG. 1. Improper positioning of a patient in bed. Note that his shoulders are internally rotated, flexed and adducted; wrists are flexed; and both the metacarpophalangeal and the interphalangeal joints are deviated toward the ulna.

expensive is the use of double bakers with suitable covering of the body to prevent heat loss.

It should be noted that heat is not without danger in the management of this disease. A small percentage of patients whose arthritis is the result of disseminated lupus erythematosus are hypersensitive not only to ultraviolet but also to infrared radiation. Also, immersion of these patients in water so that they experience an elevation in body temperature may induce an exacerbation of their disease. In instances where multisystem involvement points to the possibility of disseminated lupus, it is worthwhile to take a careful history with regard to both ultraviolet and infrared sensitivities. The denial of whirlpool therapy and generalized overheating in these patients is a worthwhile precautionary measure. Likewise, in view of the apparently increasing incidence of peripheral neuropathies in the whole group of collagen diseases and particularly in the group of patients overtreated with systemic adrenocortical hormones,[5] it is important to include testing of superficial sensation before the application of heat is prescribed. When hypesthesia is added to a state of poor skin nutrition, the dangers of skin burns are greatly increased.

MASSAGE

Massage as a form of treatment of rheumatoid arthritis is no longer highly regarded. There seems to be little, if any, clinical justification for the employment of whole body massage, as was advocated until recent years. Equally little usefulness is seen in the employment of prolonged periods of massage for reducing local swelling at or about joints, or for reducing muscular atony. Much useful and costly treatment time may be wasted on the intricacies of petrissage and effleurage. The increase in lymph flow following centripetal massage of a dog's hind limb is similar to that which follows active exercise of the limb.[2] However, in rheumatoid arthritis massage is used almost entirely for its sedative and relaxing effects rather than for its effect on lymph flow. In certain cases it may be advantageous to spend a portion of the treatment time prior to exercise in this way. It may be concluded that massage is no more than a useful minor adjunct in the physical treatment of rheumatoid arthritis, and that its use should be restricted within narrow limits of treatment time.

EXERCISE

Therapeutic exercise has become of increasing importance in the management of rheumatoid arthritis. Fortunately, many of the earlier restrictions imposed on exercise by the limitations of pain are now mitigated by the intra-articular or oral use of drugs with vastly increased antirheumatic effectiveness. This permits modification of the pre-

viously accepted rules of exercise, that a joint be exercised only to the point of pain, and only to the extent that no increased stiffness results. Correlation of exercise tolerance with changes in steroid intake can now be employed with much greater freedom. In this way, the time spent in the physical medicine department can be more fruitful than was possible when physical means were used mainly to influence the degree of systemic activity or the level of pain.

It appears to us that the uses of therapeutic exercise in the management of rheumatoid arthritis can best be summarized under these three headings: (1) prevention of joint deformity; (2) reduction of established soft-tissue deformity; (3) increased functional capacity.

1. Prevention of Joint Deformity

Proper Positioning. Emphasis has already been given to the role of the patient in the prevention of joint deformity. After suitable indoctrination in the natural history of the disease and in the part he has to play in its development, the patient is shown the likely results of neglect. Particular stress is laid on the care of the joints in which deformities can quickly develop. The patient is taught the value of correct positioning in bed, particularly during acute exacerbations of the disease. Thus, the patient is warned specifically about the dangers of assuming an attitude of flexion, adduction and internal rotation of the shoulders while lying supine in bed. This "prayerful pose" well illustrates how a potentially deforming attitude at one joint can lead to the successive development of additional deformities at both contiguous and remote joints. It can be seen in Figure 1 that the assumption of this position in bed may soon lead to palmar flexion and ulnar deviation at the wrist, and ulnar deviation at both the metacarpophalangeal and the interphalangeal joints

Excessive pillow height also can exert harmful influence on axial and limb posture. Obliteration of the cervical lordosis with compensatory increased dorsal kyphosis are only two of the dangers that result from the use of too many pillows. The adverse effect of pillows under the knees is too often thought of as being peculiar to the knee joint itself. However, it is obvious that a flexion attitude at the knee joint soon leads to the development of flexion contractures about the hip and also of plantar-flexion contractures about the ankle and the foot. Similarly, failure to consider the influence of heavy bed clothes on paretic foot muscles too frequently results in the avoidable deformities of varus and cavus of the foot. In no rheumatic disease is the importance of the patient's proper position in bed so urgent as in early rheumatoid spondylitis. In a young man with rapidly ascending ankylosis of the apophyseal joints, even a few weeks of improper positioning in bed may lead to irreversible postural deformity of appalling functional significance.

Range of Motion of Joints. It has appeared to us that the common use of so-called normal-range exercises in the instruction courses for patients with early rheumatoid arthritis is somewhat of an empiric tyranny. It is not sensible to exercise joints toward the position in which deformity commonly occurs. Too often we have seen patients confused by having to learn a complex procedure involving multiple movements of a wide variety of joints in a few hurried instruction sessions. More thorough understanding and fuller co-operation can be achieved if the patients are instructed in only a few of the functionally important aspects of joint movement. For these reasons we suggest that physicians modify and limit the exercises described in the widely circulated pamphlet put out by the Arthritis and Rheumatism Foundation[3] to suit the specific needs of individual patients. By limiting the initial instructions to a few of the more important joints, and to a maximum of two functionally important maneuvers in each joint, it has been possible to attain a much higher degree of co-operation and perseverance on

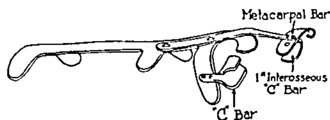


FIG. 2. Dorsal wrist cockup splint with opponens "C" bar and finger guards to prevent ulnar deviation.

the part of patients who are carrying out a treatment program at home.

Selective Muscle Strengthening. The patient is taught that he must constantly avoid the assumption of deforming "positions of ease," and that he must strengthen selectively those muscles which can prevent such deforming attitudes. Therefore, in the shoulder the patient is taught to stress full range of elevation and the maintenance of adequate strength in the abductors and the external rotators of the glenohumeral joint. In the forearm, stress is given to the maintenance of full range and strength of supination. With regard to the wrist, no attempt is made to instruct the patient in the motions of circumduction, palmar flexion or ulnar abduction. Rather, selective strengthening of the movements of wrist dorsiflexion and of radial abduction of the wrist is advised and thoroughly practiced during instruction sessions. Every attempt is made to instruct the patient in the preservation of a normal thumb web space, both by strengthening the abductor pollicis brevis and by self-administered passive stretching of the adductors of the thumb. The concept of the patient acting as his own therapist is particularly encouraged because of its usefulness in the prevention and the correction of hand deformities due to muscle imbalances. As an example, the early atrophy seen in the first dorsal interosseus muscle can often be reversed by the patient's use of graded resistance applied by the opposite hand or even by a rubber band placed about the fingers. Where patients have made conscientious efforts to carry out the few simple technics of exercise learned in these instruction sessions, there has been a gratifying reduction in the extent of joint deformity. But such willing cooperation is secured most readily when the patient has an adequate understanding of the purpose of therapeutic exercise in prophylaxis and when his attention has been focused on only a few functionally significant muscle groups.

Orthetic Devices. Adequate discussion of splints and braces is obviously beyond the scope of this paper, and we propose merely to discuss one narrow aspect of splinting in rheumatoid arthritis. In no other location is the stigma of a disease more obvious than in the twisted hands of a patient with advanced rheumatoid arthritis. Too often, patients have suffered because of the clinician's acceptance of hand deformity as a usual and even a classic manifestation of the disease. An unfortunate hiatus exists between the internist's knowledge of the systemic disease and the orthopaedist's awareness of deformity and methods for its correction. Obviously, there is a great need to arouse interest among physicians, particularly among generalists and internists, in early detection and correction of deformity, so that fewer patients will be allowed to deteriorate to the state of irreversible deformity. As a preliminary to treatment it will be necessary to disseminate the knowledge that there is no "typical rheumatoid deformity of the hands," and that many established deformities are as much the result of neglect as they are of the ravages of the disease.

As an illustration of the values of simple prophylactic splinting, there is none finer than in the use of an inexpensive hand splint for the prevention of thumb web contracture and of ulnar drifting at the metacarpophalangeal joints (Fig. 2). By the provision of a simple opponens "C" bar for preservation of the thumb web, and of suitable guards at the ulnar sides of the index and the fifth phalanges, it has been possible to prevent impending functional losses in a majority of patients with rheumatoid arthritis. By protection of the index- and the little-finger phalanges from ulnar luxation, we have at-

tempted to minimize at least two deforming influences. The splint used is a modification of the well-known aluminum Warm Springs device, with added curved guards on the ulnar borders of the proximal phalanges. Our experience with the protective glove splint advocated by Kendall and Rose[9] has not been very satisfactory, and we have abandoned its use. Again, it is important to impress on the patient that the main usefulness of any protective device for the hand is during those times when he himself is unable to perform corrective exercises. At every opportunity he is advised to develop his own muscular "splint" by the use of active and resistive exercises of the muscles which prevent ulnar shifting of the proximal phalanges.

2. Reduction of Established Soft-Tissue Deformity

Passive Stretching. In the presence of an already established fibrous contracture about a joint, graduated passive stretching is often considered as an accepted form of treatment. However, whether applied manually or by means of corrective orthopaedic appliances, reduction of contracture is, at times, a risky procedure. In patients with considerable subchondral rarefaction, and particularly in those receiving excessive doses of adrenocortical hormones, the dangers of fracture are considerable. Accordingly, the cardinal rule of slow mobilization of contracture has particular application in this disease. Stretching is of value in the correction of early "soft" contractures in the thumb web, in the collateral ligaments of the finger joints, in the external rotators of the hip, and in the iliotibial tract and the extensors of the toes. As a preliminary to passive mobilization of a joint, the use of ice packs is sometimes superior to the customary practice of heating.

Orthetic Devices. Again, the wrist splint with the curved finger guards to prevent and to correct ulnar drifting of the wrists and the fingers is useful at this stage as a night splint. Once the deformity has progressed beyond that point at which muscular action



Fig. 3. Hand splint with lumbrical bar, swivel thumb and dynamic wrist, finger and first dorsal interosseous units.

reduces rather than increases the deformity, dynamic splints are often useful. However, these splints are cumbersome and expensive, and patients are prone to discard them; this should be considered before ordering them. A good example of such a splint is shown in Figure 3. These splints can also be designed with interchangeable dynamic or assistive attachments to be used during the day and supportive or resistive attachments for positioning at night.

Shoes should be well built, Oxford type, with a total heel surface of about 4 square inches. A leather metatarsal bar just posterior to the metatarsal heads may reduce discomfort, as may also a longitudinal felt arch support and a soft pad under the heel.

Corrective Surgery. It may seem somewhat presumptuous to discuss the role of surgery in this account of conservative physical management of rheumatoid arthritis. On the other hand, there will continue to be unfortunate gaps in management as long as physicians view surgical treatment, either in prophylaxis or in correction of deformity, as being radical. As has been pointed out so cogently by general surgeons, the term "radical" should be replaced by "adequate," as descriptive of the surgical contribution to this disease. Thus, the surgical replacement of extensor tendons which have slipped toward the ulna from the dorsum of the metacarpophalangeal joints should be considered

the only adequate treatment of the deformity. It is clinical folly to persist with unrewarding exercises and splints as means of correction when definitive surgical measures are available. Relatively simple orthopaedic procedures, such as the release of contractured thumb adductors and the transfer of extensor tendons radially on the hand are too often deferred until unnecessarily prolonged trials of conservative management have been found to be unrewarding. Examples from our own experience (W. J. T.) which illustrate the role of surgery in conservative management are provided by the following case reports:

Case 1. The patient, a little girl 6 years old, has had rheumatoid arthritis for more than 3 years with recurrent hydrarthrosis in both knees. Repeated aspirations, yielding 25 to 45 ml. of joint fluid, had been performed at intervals of from 1 to 10 months. Despite intensive physical therapy, the use of pull-down splints, and repeated instillation of steroids intra-articularly, the child had developed bilateral knee flexion contractures of approximately 20°. These contractures were resistant to all nonsurgical methods of mobilization. On careful examination, tight iliotibial bands were found in both legs and were considered to be contributory to the contractures at the knees. Following bilateral Yount fasciotomy there was prompt reduction not only of the knee flexion contractures but also of a developing flexion deformity of both hips, as can be seen in Figure 4.

Case 2. The patient, a 43-year-old housewife, had had active polyarticular disease for some 12 years. During the 6 months before she was examined in our clinic, she had noted rapid deterioration in the functional capacities of the right hand due to ulnar drifting of the wrist and the phalanges. On examination the flexor carpi ulnaris tendon on the right side was seen and felt to be contractured Moreover, when this tendon was deliberately tautened by passive radial displacement of the wrist, the muscle belly of the abductor digiti quinti was found to be fibrotic and apparently foreshortened Attempts at correction of these deformities by splinting and exercise were continued for 8 weeks without success Finally, following surgical release of the flexor carpi ulnaris there was a satisfactory reduction in the contracture of the abductor digiti quinti When the patient was seen 2 years after surgical correction, the appearance of this hand was far superior to that of the hand treated by conservative means.

These cases emphasize the fact that corrective surgery is often the only appropriate conservative treatment for prevention or reduction of joint contracture. The role of minor surgical procedures in early prophylaxis has been overlooked by physicians far too long; either they are unaware of potentially deforming attitudes or are uncertain of the surgical contributions possible in the correction of joint deformity. Here again, as in the over-all supervision of the musculoskeletal aspects of poliomyelitis, there is a real need for the orthopaedist to acquaint his physician colleagues with the value of early surgical reduction of incipient deform-

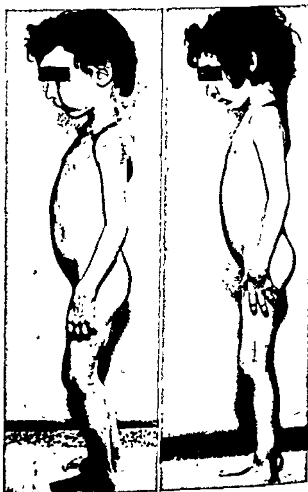


FIG 4. Six-year-old child with rheumatoid arthritis before and after release of iliotibial band bilaterally (Treanor, Grant and Psaki· Arch Phys. Med 37:699-705)

ity. Consideration of surgical treatment should take an important place in the physician's plans for conservative treatment of rheumatoid arthritis, even in the early stages of the disease.

3. Increased Functional Capacity

For patients with already established contractures the chief purpose in clinical management becomes the optimal utilization of residual capacity. Muscle atrophy, due either to mechanical distention of the joint or to increase in the inhibitory relays from an inflamed joint, must be combated with every possible means. The usefulness of strengthening exercises is often reduced by an attendant increased inflammatory reaction in the joint. In such instances, exercise tolerance can usually be increased by repeated intra-articular injections of corticosteroids. Means of reducing muscle atrophy are of special significance in those joints which are concerned with ambulation, either with or without the aid of crutches. Thus, the occurrence of atrophy in the elbow, the wrist, the hip and the knee extensor muscles can seriously impede all efforts at practical ambulation. The benefits of earlier instruction in selective strengthening of such functionally important muscle groups become increasingly apparent in the 10 to 20 per cent of patients in whom the disease pursues a rapid course. Preservation of adequate joint range and of sufficient strength in the muscles needed in ambulation then becomes the minimum requirement for functional independence.

A feature of rheumatoid arthritis which is too often overlooked in assessment of disability is the functional significance of myogenic disease or so-called secondary fibrositis. This component is frequently a more serious cause of disability than is the extent of synovial hypertrophy or of cartilaginous or osseous destruction When morning stiffness persists as long as 1 hour and is accompanied by a persistence of muscle "jelling" after sitting for about as long a time, the effectiveness of the rheumatoid patient as a worker is grievously impaired. When easy fatigability is added to the twin terrors of morning stiffness and "jelling," the patient's capacity for sustained muscular effort is not sufficient to pursue his regular employment. With job insecurity added to ever-present articular and periarticular symptoms, it is small wonder that patients with this protracted disease not infrequently become labeled with every new term in psychiatric nomenclature. It is basic to the management of rheumatoid arthritis that the myogenic symptoms must be managed properly before the patient will assume his full role. In this regard, careful timing in administration of antirheumatic drugs and the use of simple home measures, such as early morning hot showers and contrast baths, often yield remarkable functional benefits. Thus, the duration of morning stiffness may be reduced to less than 30 minutes if the patient takes a dose of salicylates about 15 minutes before rising and if he later takes a hot bath or shower. It is unfortunate that such disproportionate clinical interest has been spent on "primary fibrositis" while the investigation and the treatment of the fibrositis associated with a variety of systemic diseases, and particularly with rheumatoid arthritis, have been largely neglected.

Finally, when all efforts at management have failed to prevent crippling joint deformities, the physician's responsibility shifts to the provision of suitable mechanical substitutes for lost functions. A sizable catalogue of commercially available aids to self-help has been prepared and widely distributed.[1] With a range extending all the way from raised toilet seats to electrically driven wheel chairs, such a formulary of human engineering aids to the handicapped will soon become an important reference work for physicians interested in rheumatoid arthritis. In the presence of already established joint deformity, use of these self-help devices often results in worthwhile increments of functional capacity.

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Tractamento de Precoce Arthritis Rheumatoide per Medios Physic

Summario in Interlingua

Il non es possibile sublinear troppo frequentemente le rolo del patiente mesme in le tractactamento de arthritis rheumatoide. Il ha essite constatate que le patientes collabora plus efficacemente in le therapia a longe vista, si illes ha essite indoctrinate appropriatemente in le historia natural del morbo e in le preservation de un adequate function articular. Clar instructiones es date con respecto al importantia de evitar certe "positiones de conforto" e de reinfortiar selectivemente le functionamento de certe gruppos de musculos. Attention special es prestate a un numero restringite de articulationes e a solmente un o duo functionalmente importante motiones in omne articulation individual. Le uso, al domicilio del patiente, de calor e massage es incoragiate sed solmente como adjunctos minor al persistente adherentia del patiente un pı gramma de exercitios active. Dispositiv orthotic es de valor in le prevention deformitate carpal o digital. Intervention de reconstruction chirurgic deberea ess reguardate como un parte integral de om programma de tractamento conservatori. le presentia de jam establite deformitat articular, augmentos significative de capa tate functional pote resultar ab le uso d semper plus numerose apparaturas e disp sitivos de auto-adjuta. In le interesse un meliorate therapia de precoce arthri rheumatoide, il es extrememente importan diffunder inter crescente numeros de med cos un plus alte grado de interesse pro problemas e un plus profunde comprensic del principios general in le tractamento ille condition.

8

A Review of Denervation Atrophy with Some Comment on the Results of Electric Stimulation in Humans and in Animals

KHALIL G. WAKIM, M.D.*

SALIENT STRUCTURAL FEATURES OF MUSCLE

As an introduction to the chronologic clinical picture and course of denervation atrophy, a review of certain salient anatomic features, essential for the basic understanding of functional integrity of skeletal muscle, would be helpful to the orthopaedist whose corrective surgical treatment often is aimed at maintenance or restoration of normal muscular function.

The human body contains 434 muscles,[30] which make up about 45 per cent of the weight of the adult body and include about 250,000,000 individual muscle fibers. Each muscle consists of a certain number of fibers organized into primary, secondary and tertiary bundles. A framework of connective tissue covers and binds together these bundles into fasciculi. The fibers run parallel within a fasciculus. The number of fibers in fasciculi of the same muscle varies greatly.

The three components of muscle fibers are (1) the myofibrils, or sarcostyles, which are the contractile elements, (2) the sarcoplasm, which is the undifferentiated protoplasm within which the myofibrils move, and (3) the sarcolemmal sheath, which encases both myofibrils and sarcoplasm. Each muscle fiber is a multinucleated cell of variable width and length, with an average diameter of about 50 microns and a length varying from a few millimeters to more than 30 mm. Lockhart and Brandt isolated muscle fibers 34 cm. in length from the sartorius muscle of man, which itself is 52 cm. in length. Fibers of skeletal muscle usually do not branch or anastomose. Each fiber is enclosed within a fine sheath of sarcolemma and contains a great number of myofibrils embedded in sarcoplasm. The sarcolemma is a thin transparent membrane surrounding the sarcoplasm. According to Kite, the sarcolemma is elastic, continuous and adherent to the surface of the entire muscle cell. It can be vitally stained with isamine blue or Janus green.[9]

Beneath the sarcolemmal membrane of the muscle fiber lie a number (up to several hundred) of flattened nuclei, which are the sarcolemmal, or muscle, nuclei. They range from 1 to 3 microns in width and 5 to 12 microns in length; they contain 1 to 3 nucleoli. They differ from the nuclei of

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form the perimysium. Like the epimysium, *the perimysium is formed of collagenous,* reticular and elastic fibers, with fat cells.[1]

The endomysium is a delicate network of fibrous tissue that extends from the perimysium into the primary muscle bundles and surrounds each fiber. *Capillaries,* nerve filaments, fibroblasts, histiocytes and mast cells are present in the endomysium.[1] The amount of elastic fibers in the interstitial connective tissue varies with the functional activity of the muscle. Continuously active muscles like those of the eye, tongue and diaphragm have an abundance of elastic fibrils in the endomysium.

The constituent elements of the tendon are glistening white cords of connective tissue that possess toughness and pliability. The remarkable inelasticity of tendons is manifested by breaking of bones or rupture of muscles before a normal tendon yields to a force.[1] Growth and repair of tendons occur by proliferation of fibroblasts and formation of new collagen.

EFFECTS OF DENERVATION

A unique feature of the fibers of skeletal muscle is their dependence for structural and functional integrity on maintenance of anatomic continuity with the central nervous system. Immediately after disruption of the nerve supply to skeletal muscle, the muscle cannot receive impulses from the central nervous system nor can it take part in the organized activity initiated by the nervous system. This isolation from the central nervous system imposes on muscle certain chronologic changes culminating in the clinical picture recognized as denervation atrophy. After disruption of the nerve supply to skeletal muscle, its fibers undergo qualitative and quantitative *morphologic, chemical* and functional alterations. These changes occur in the muscle cell itself, while the constituents outside the muscle fiber, such as the connective-tissue sheaths, blood vessels and *extracellular fluid and lymph, undergo* minor changes, if any.

After severance of a motor nerve, its *distal portion* remains excitable until the axis cylinders begin to break up into fragments. This usually occurs within about 72 hours after continuity with the nerve cell is broken. For about 10 days after degeneration of the distal portion of the excised motor nerve has commenced, the motor end-plate retains its electric excitability despite inability of the muscle to take part in central nervous activity. During this period, the portion of axis cylinder in the motor end-plate disappears, after which the excitability of the region decreases and becomes the same as that of the remainder of the muscle fiber. This reduction in excitability resulting from degeneration of the motor nerve can be easily demonstrated by failure of applied faradic current to excite the degenerated muscle. However, the slow galvanic current is still effective. The chronaxie is prolonged. These manifestations are designated as the "reaction of degeneration." The excitability to galvanic current increases, which means that less amperage is needed to excite. There is polar reversal; the strength-duration curves become altered and show discontinuities The initial increase in galvanic excitability is accompanied by increased sensitivity to acetylcholine and to potassium. Spontaneous fibrillary twitchings appear soon after complete disappearance of the axis cylinder at the motor end-plate. Fibrillation appears at about the fifth to the seventh day after severance of the nerve and disappears days or even weeks after re-innervation.

A number of investigators[5,8,10,31,34,40-42] have studied the histologic changes induced in skeletal muscle consequent to denervation. Early during the first week after denervation, *the subsarcolemmal nuclei* in muscle gradually become plump and rounded and no longer appear elongated, flattened and compressed. The nuclei migrate inward into the muscle fibers and take up *a more central position* among the myofibrils. Tower[41,42] noted that the earliest

changes occur near the motor end-plates. Altschul[3] considered a reduction in interstitial pressure as the basic cause for the increase in nuclear size. Enlargement of the nucleoli makes them more prominent. In due time the muscle nuclei appear like a string of beads connected by fine strands of nucleoplasm, which is highly suggestive of amitotic division. My associates and I[5,37,43-45] noted an increase of more than 200 per cent in the number of nuclei per unit area 40 days after denervation.

The arterioles and capillaries in denervated muscle are congested and thickened; vascular occlusion sometimes occurs. The endomysial connective tissue is more prominent, but an increase in number and size of fibroblasts is doubtful. Histiocytes, clasmatocytes and lymphocytes become more prominent. The muscle fibers later become rounded instead of polygonal, and their diameter is reduced. Loss of myofibrils causes less uniformity in the diameter of muscle fibers. The subsarcolemmal nuclei become still more enlarged and vesicular.[3] Some muscle fibers show an altered staining reaction, vacuolization, fragmentation and invasion of the sarcoplasm by macrophages. This process is designated as "degeneration" and is irreversible in contrast with atrophy, which means reduction in bulk and which is reversible. Connective tissue is more prominent and scattered plasma cells, lymphocytes and histiocytes are found.

At the end of 2 months, the reduction in diameter of the muscle fibers is far advanced—the fibers being practically half their normal size—and is more prominent in some fascicles than others. Both sarcoplasm and myofibrils share in this atrophy. The striations, both longitudinal and transverse, are intact. At the end of 4 months, the atrophy progresses less rapidly. In some fibers, the nuclei become clumped into groups. Degeneration of isolated fibers becomes more prominent. The transverse striations become less distinct in some zones, but the longitudinal striations remain prominent. The contractile tissue shrinks to small tubes containing a row of nuclei and some poorly staining fibrils. In the end, only a string of darkly staining, rounded muscle nuclei remains.

In the regions of most advanced degeneration, columns of fat cells interspersed with strands of inert fibrous tissues take the place of the muscle tissue. The muscle spindle is well preserved for many months after denervation. Fragmentation is a late stage in denervation atrophy. At some stage of the atrophic process, the changes become degenerative. Durante suggested this as the metamorphosis that represents adipose-tissue or fibrous-tissue transformation, for which Adams and associates found no supportive evidence.

Denny-Brown considered the final stage of neural atrophy as a dystrophic process in which some factor supplied to muscle is lacking. This factor is essential for the formation of new myofibrils, and its absence is reflected in gradual loss of the tensile structures in the contents of the fibers. Adams and co-workers stated that muscle tension, instead of stimulating the production of new myofibrils, appears to accelerate the dystrophic process. Tower[42] described the transformation of muscle fibers to fibrous tissue as "fibrotic dedifferentiation." By fading of the cross striation with conservation of the fibrils and by slimming of the nuclei, large regions of muscle tissue become transformed into fibrous tissue. Altschul[3] was convinced of the replacement of muscle fibers by adipose tissue and suggested that both fibrous and fatty tissues were the result of metaplasia of muscle fibers. Adams and associates have not observed any transitional stage involving either fibroblasts or fat cells. They considered that the progressive replacement by adipose tissue that ultimately occurs is due to transformation of fibrous interstitial tissue or is from undifferentiated mesenchyme. Bowden and Gutmann found no evidence of fibrotic dedifferentiation in human muscles.

Thus, the histologic picture of denervation atrophy of muscle is exhibited in three distinct phenomena, namely: (1) atrophy, with reduction in size of fibers but preservation of cross and longitudinal striations; (2) degeneration of scattered but progressively numerous muscle fibers; and (3) ultimate replacement by connective-tissue cells, with variable increase in the amount of reticulin in the endomysium and collagen in the perimysium and aponeuroses.

The degree of reduction in size and weight of denervated muscle generally is considered to be about 30 per cent in the first month and 50 to 60 per cent at the end of 60 days; atrophy progresses more slowly thereafter, reaching a fairly constant value of 60 to 80 per cent at 120 days or longer.[40] Different muscles show significant deviation from these averages. The small muscles of the larynx reach an advanced state of atrophy 2 weeks after excision of the recurrent laryngeal nerve, whereas the external anal sphincter is extremely resistant to atrophy after denervation. Furthermore, despite histologic and electric proof of absence of regeneration of the nerve, various parts of a muscle may be in greatly different phases of atrophy and degeneration.

My associates and I[5,37,43-45] followed the changes in weight of muscle for about 2 months after denervation. Comparison of normal with denervated gastrocnemius, plantaris and anterior tibial muscles revealed negligible reduction in weight during the first 3 days after denervation; however, the reduction in weight after 40 days averaged 75 per cent. Altschul[2,3] noted reduction of as much as 64 per cent in the weight of muscles of cats and rabbits after 40 to 113 days of denervation. It is estimated that the nonmuscle component in muscle, which does not belong to the substance of the muscle fiber proper but to the connective-tissue stroma in the framework of muscle, makes up 10 to 25 per cent of the weight of muscle. Therefore, a loss of 75 per cent of the weight of a muscle, in light of the fact that nonmuscle components do not take a significant part in the atrophy, denotes a tremendous reduction in the muscle tissue itself. This reduction in weight of denervated muscle evidently is associated with reduction in size of the individual muscle fibers. We noted that an average of 68 per cent more muscle fibers could be counted microscopically per unit area in cross sections in denervated muscles than in intact muscles. Measurements revealed a 41 per cent reduction in the diameter of individual muscle fibers of the gastrocnemius muscle 40 days after denervation.

A feature that we observed frequently but for which we have no explanation is the spottiness and variation in degree of the atrophy despite the fact that the nerve supply to the entire muscle under study was excised at the same time. For example, many sections made from muscles denervated 30, 40 and 60 days previously often show zones of varying degrees of atrophy intermingled with zones of slight atrophy or none whatsoever.

Chemical Changes After Muscle Denervation

Hardly any change in chemical constituents can be detected in the first 3 to 7 days until the fragments of the axis cylinder have disappeared from the end-plates. Thereafter, a striking change is the increase of calcium, which is doubled by the end of the first month of denervation.[22,42] The content of chloride also mounts steadily. After a slight increase in the first 3 days, potassium declines progressively. Phosphocreatine and adenosine triphosphate decline rapidly. Creatine is slowly and progressively lost. Hoagland found no significant differences between the changes in atrophy of denervation and those in disuse atrophy (tenotomy or immobilization by plaster cast); the total protein content, precipitable myosin, creatine, glycogen, phospholipin, oxygen, glucose, carbon dioxide and succino-dehydrogenase activity were decreased in both. These changes

are an expression of the relative loss of muscle cells and increase in connective tissue.

THEORETIC CAUSES OF DENERVATION ATROPHY

The fundamental cause of denervation atrophy is unknown; consequently, several theories have been proposed to explain the basis for atrophy. The absence of "trophic" influence of the motor nerve on muscle often has been given as an explanation for the atrophy that follows denervation; however, it is extremely difficult to evaluate the exact significance of the term "trophic." Other workers brought forth the concept that the persistent activity induced by fibrillary twitches led to an exhaustion atrophy. However, the following findings refute this concept: (1) fibrillation is absent after tenotomy and immobilization, yet the rate of atrophy is not different from that after denervation with fibrillation; (2) atrophy is not retarded by drugs such as atropine and quinidine that are known to reduce or abolish fibrillation; (3) drugs such as methacholine (mecholyl) chloride, potassium chloride and neostigmine (prostigmin) that are known to enhance fibrillation apparently do not increase the rate of atrophy; (4) electric treatment of denervated muscle activates the muscle but delays rather than enhances the rate of atrophy.

Thus, the basic mechanisms and causes of atrophy remain at present in the realm of speculation.

EFFECTS OF THERAPEUTIC ELECTRIC STIMULATION

To date there is no unanimity regarding the effects of therapeutic electric stimulation on denervated skeletal muscle. A few investigators have not obtained beneficial effects from such treatment, whereas many have presented evidence of benefit. No indication exists as to the number of stimuli to be applied per unit of time or as to the duration and frequency of the periods of electric stimulation. No suggestion has been made as to whether therapeutic electric stimulation should be given once or more per day or per week.

Many suggestions have been presented regarding the influence of electric stimulation on the course of denervation atrophy. In 1841, Reid suggested use of electric stimulation as a treatment of paralyzed muscles. More recent work[14,19,20,23,38] has provided convincing evidence that electric stimulation retards the loss of weight and strength of denervated muscle. Kosman and associates suggested that appropriate electric stimulation leads to a stronger and heavier muscle during both denervation and recovery. Solandt and co-workers reported that a 25-cycle alternating (sinusoidal) current produced the best results with respect to retention of weight, a 60-cycle alternating current being second best. They found galvanic and faradic currents inferior to the 25-cycle and 60-cycle sinusoidal currents. A linear relationship was found between effectiveness and the number of daily treatments.

Fischer obtained best results when electric stimulation was started immediately after denervation. Gutmann and Guttmann[20] observed early treatment to be more effective than late therapy in retarding both atrophy and fibrosis, and that treatments given twice weekly were ineffective as compared with daily treatment.

Wehrmacher and associates noted electric stimulation to be most effective in retarding atrophy when the muscles were subjected to the maximal stretch permitted by anatomic attachments and restrained by weights to allow only minimal shortening during treatments. They stimulated the muscles electrically for periods varying from 3 to 180 seconds and concluded that the effectiveness of such treatment was independent of its duration. Electric stimulation failed to retard the atrophy that follows tenotomy.

Eccles found that periods of stimulation ranging from 2 seconds to 2 hours daily

were equally effective in preventing total disuse atrophy. Osborne and associates used sinusoidal current at a modulation frequency of 24 times per minute. The treatment consisted of stimulation for 10 minutes, 6 days each week. They concluded that atrophy can be greatly retarded or even prevented by means of such treatment. Grodins and co-workers used a frequency of 25 cycles that was modulated to give 40 contractions per minute.

In evaluating the effects of percutaneous electric stimulation on the circulation in the paralyzed extremities of patients, my associates and I[46] noted that all observations made on stimulated spastic extremities demonstrated a definite increase of blood flow averaging 111 per cent more than the control value (range of 32 to 340%). Similarly, the blood flow in stimulated extremities of normal persons showed an increase in blood flow averaging 86 per cent more than in controls. Electric stimulation of flaccid atrophied muscles gave weak contractions or none at all and consequently produced insignificant changes in blood flow. This was considered strong evidence that the increase of blood flow was chiefly contributed by the activated muscles.

In a study of the influence of varying the frequency of electric stimulation on the blood flow in the stimulated extremity, I[43] varied the stimuli from 4 to 256 per second. The intensity was the same for all frequencies and was fixed at a point at which the stimulated muscles gave the most vigorous response The frequency of 16 impulses per second most often gave the greatest increase in blood flow. However, frequencies of 8 and 32 impulses per second gave sufficiently high increases in blood flow. This work suggested that, if increases in blood flow could be considered the basis for the beneficial effects of electric stimulation of muscles, a frequency of about 16 impulses per second might be considered as being optimal.

In another study, my associates and I[37] found that daily electric stimulation of denervated muscle partially checks the progress of denervation atrophy. The retardation of atrophy was enhanced and prolonged when the muscles were placed on tension and were made to contract against resistance during stimulation. The denervated stimulated muscles had fewer nuclei and fewer fibers per unit area than did denervated unstimulated muscles. The fibers of the denervated stimulated muscles were larger than were those of denervated unstimulated muscles. At the end of 60 days, the denervated stimulated muscles of the dog were darker red than were denervated unstimulated muscles.

Another series of studies[44] was performed to determine the influence of electric stimulation on the work output and endurance of denervated muscle. Therapeutic electric stimulation enabled denervated muscles of albino rats to do more work than the corresponding denervated unstimulated muscles of litter mates. Electric stimulation even for extremely short periods was helpful. The total work output of denervated muscle, stimulated for only 5 minutes each half hour, averaged 40 per cent of normal. As far as work output, endurance and optimal stimulation were concerned, stimulation for 30 minutes once daily had slight beneficial effect, whereas stimulation for 30 minutes twice daily had greater beneficial effect. Stimulation for 5 minutes every half hour for an 8-hour day, starting at 8 A.M. and continuing till 5 P.M., with 1 hour of rest at noon, had substantially as much beneficial effect as did longer periods of stimulation each half hour.

However, it is important to remember that electric stimulation, although it prevents the extreme loss of power usually seen in denervated muscle, does not completely replenish the power of denervated muscle to do work such as it would do if its connections with the central nervous system were intact. Stimulated denervated muscle became more efficient than the unstimulated

denervated muscle, but neither could do as much work as comparable intact muscle. Denervation apparently deprives muscle of something that so far can be replenished only by successful complete re-innervation. Similarly, electric stimulation reduces the degree of atrophy and delays its course, but does not completely prevent it.

SUMMARY

Changes in skeletal muscle during denervation atrophy are physical, chemical, electric and functional. The physical changes include generalized loosening of the normally compact arrangement of muscle fibers, increase in the number of subsarcolemmal nuclei, reduction in size of muscle fibers, dilatation of blood vessels, perivascular thickening and, at times, occlusion of vessels, and progressive increase of connective tissue, which permeates the spaces between the muscle fibers; finally, in the absence of nerve regeneration, fibrosis may occur, with practically complete replacement of muscle by fibrous tissue.

The chemical changes in muscle include decrease in phosphorus, phosphocreatine, creatine, glycogen, potassium, myosin and other noncollagenous proteins. Some increase occurs in the collagenous protein and in the calcium and water content of denervated muscle. Denervated muscle becomes highly sensitive to acetylcholine and to radioactive potassium.

Changes in the response of denervated muscle to electric stimulation include difficulty in eliciting response to faradic current of usual intensity, the production of a poorly maintained tetanus by direct (galvanic) current, lengthening of the chronaxie, presence of the reaction of degeneration and polar reversal. The curves of duration and strength become altered and show discontinuities.

Fibrillations resulting from spontaneous contractions of individual muscle fibers appear shortly after denervation and persist until re-innervation occurs or until the muscle fibers become replaced by fibrous tissue. Functional disturbances consequent to denervation include easy fatigability, loss of strength, tone and endurance, and inability to induce voluntary activation of skeletal muscle.

Therapeutic electric stimulation applied daily to skeletal muscle soon after denervation benefited the work output and endurance of the involved muscles, but did not completely replenish the power of denervated muscle. Stimulated denervated muscle became more efficient than unstimulated denervated muscle, but neither could do as much work as comparable intact muscle. Denervation deprives muscle of something that can be replenished only by successful complete re-innervation.

CONCLUSIONS

1. The atrophy consequent to denervation of skeletal muscle is associated with important physical, chemical, electric and functional changes.

2. During denervation atrophy, skeletal muscle loses weight, color, strength, endurance and efficiency. If it is untreated and fails to become re-innervated, it finally undergoes fibrotic replacement.

3. Electric stimulation of skeletal muscle, whether direct or through the nerve supply, increases the flow of blood through the activated muscles.

4. Electric stimulation improves the work output and endurance of denervated muscle. It retards, but does not completely prevent, denervation atrophy.

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Un Revista de Atrophia per Disnervation, con Alicum Commentos Relative al Resultatos de Stimulation Electric in Humanos e Animales

Summario in Interlingua

In atrophia per disnervation, le musculo skeletic suffre alterationes physic, chimic, electric, e functional. In le absentia de regeneration nerval, le alterationes physic resulta in le reimplaciamento practicamente complete del histos muscular per histos fibrose. Le alterationes chimic consiste de un reduction del majoritate del constituentes, con un augmento de proteina collagenose, de calcium, e de aqua. Le alterationes electric include le absentia de reaction a currentes faradic, imperfecte mantenentia de tetano sub le impacto de currentes galvanic, e le reaction de degeneration. Le alterationes functional include rapide fatigabilitate, perdita de fortia, de tono, e de resistentia, e le incapacitate de effectuar le activation voluntari de musculos skeletic.

Le stimulation electric de musculos disnervate, interprendite pro objectivos therapeutic, augmenta le provision de sanguine e meliora le capacitate pro labor, sed illo non restabli completemente le potentia normal. Le stimulate musculo disnervate es plus efficace que le non-stimulate musculo disnervate, sed ni le un ni le altere es capace a laborar como un comparabile musculo intacte. Le disnervation priva le musculo de un factor que pote esser reimplaciate solmente per le complete re-innervation.

9

Rehabilitation of the Amputee

Lower and Upper Extremities

HENRY H. KESSLER, M.D., PH.D.*

THE LOWER-EXTREMITY AMPUTEE

BACKGROUND

All writing, whether literary or scientific, is autobiographic. One soaks up the impressions of a lifetime and refines them into a few provocative generalizations. Therefore, what I have to say will reflect the intuitions, the prejudices and the impact of my years in the rehabilitation movement. This movement began 40 years ago in this country, although it had a long and amorphous history over the centuries. The Napoleonic Wars and the American Civil War contributed to the concept of rehabilitation, but the care of the victims of those wars was sporadic and unorganized. A systematic program for the care of the war injured was hardly evident.[13]

Whatever the origin of the word or the concept of rehabilitation, two influences helped to shape its character and its development in this country. The first was the establishment of the Red Cross Institute in 1917 in New York City under the stimulation and the direction of Donald McMurtrie. This center was equipped with a complete artificial limb factory and with printing presses and other facilities for occupational activities which would help to restore the injured and war-disabled to a normal place in society. It also contained a library in which the achievements of the French and British in this field were carefully recorded. Its greatest influence was as a center for the dissemination of information concerning rehabilitation of the war-disabled.

The Red Cross Institute had much to do with the establishment, in 1919, of the first rehabilitation center under government auspices in this country—namely, the New Jersey Rehabilitation Clinic at Newark. It had much to do with the legislation which formed the basis for the establishment of the New Jersey Rehabilitation Commission. The Red Cross Institute changed its name and it is now known as the Institute for the Crippled and Disabled in New York City.

A second influence was the work of Dr. Fred H. Albee at the United States General Hospital No. 3 at Colonia, N. J. It was in this institution that Dr. Albee developed his ideas not only for the orthopaedic and the surgical management of war injuries and their sequelae but for the comprehensive services which came to be called physical restoration and rehabilitation. Dr. Albee became the Chairman of the New Jersey Rehabilitation Commission in 1919 and served in that capacity until 1942. It was at his suggestion that I came on in 1919 as Assistant Medical Director of the New Jersey Rehabilitation Clinic. I also spent a year at the Institute for Crippled and Disabled, learning how to make artificial limbs.

* From the Kessler Institute for Rehabilitation, West Orange, N. J.

The establishment of the New Jersey Rehabilitation Clinic in the spring of 1919 was the first governmental effort in this country to take care of the needs of the civilian disabled. In addition, though much was being done for the war disabled, this was the first effort on the part of any public or private agency to undertake a comprehensive program for their rehabilitation. Not until 1920 did the Federal Government pass the Vocational Rehabilitation Act, indicating an interest in such a program. However, the Vocational Rehabilitation Act placed greatest emphasis on the vocational rehabilitation of disabled civilians. Only a minor interest was shown in their physical restoration, an interest chiefly concerned with the provision of artificial limbs.

For many years the educational and vocational orientation was the major emphasis in all governmental rehabilitation efforts. By providing grants-in-aid to the states, the Federal Government did stimulate the establishment of rehabilitation centers and programs in the various states.

Not until 1943 did a change in orientation occur. The New Jersey program always had insisted on a balanced type of service in which physical restoration came first, followed by vocational guidance and training, and finally placement of the disabled. The Federal Government, in 1943, affirmed this idea by including in their services physical restoration plans. From then on the slogan was "Do not train a man around his handicap; get rid of his handicap."

While the Federal Government, in conjunction with the states, proceeded in an evolutionary and slow manner in the development of rehabilitation services in this country, there was very little medical acceptance and not a little medical resistance to the program Not until World War II did this acceptance become crystallized into the various programs of the Armed Services and the Veterans Administration.[7]

Of course, every doctor believed in rehabilitation, but he used a different word to convey the philosophy behind these services. The doctor used the word "cure" to express his interest in this program. By this word he meant it was his responsibility to relieve the patient's symptoms, restore his function and return him to his job, his family and his community as a normal human being. In pneumonia, appendicitis and even in simple fractures, these objectives are achieved by the doctor working by himself, practically with one hand tied behind his back.

However, when a man has lost a leg, suffered a stroke, is paralyzed by a spinal-cord injury or polio, the doctor then needs not only his own two hands but many other hands as well. To restore these people to a useful place in society is his aim, but one that cannot be achieved without the aid of many others. He needs now not only the practical help of the nurse who will teach the patient how to be independent, but also the physical therapist, the occupational therapist, the brace-maker, the vocational counselor, and many other public and private agencies, if the patient is again to become a productive member of society. The doctor's responsibility must now be shared, since medical treatment alone will be inadequate in solving the many social and economic problems that have developed out of the disbility. The patient is now a displaced person in society, and the aim of rehabilitation services is to resettle him again in society.

THE AMPUTEE

Among the large group of the disabled who seek the services of rehabilitation agencies, the amputation case is one that requires careful consideration. Many rehabilitate themselves because their educational or occupational resources are unimpaired by the handicap, or because they have well-adjusted personalities, or because of fortuitous circumstances. On the other hand, a larger number are unable to help themselves. For them employment is facilitated by providing artificial appliances. By replacing the lost member, the prosthesis serves to remove the

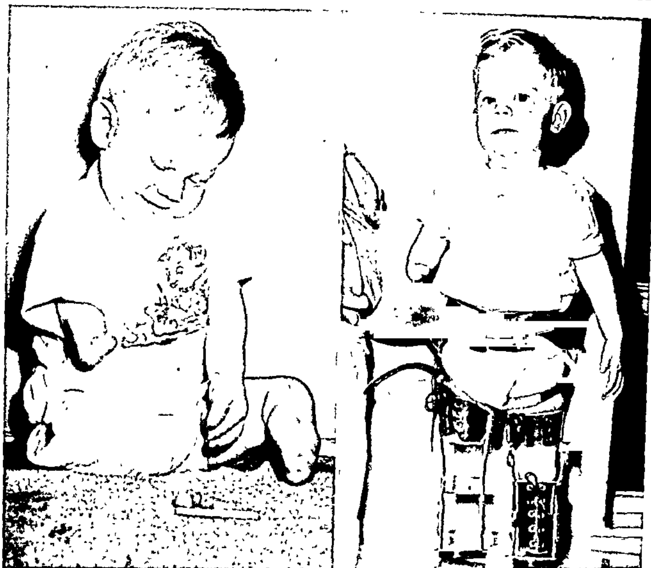


FIG. 1. (*Left*) Congenital absence of the right lower extremity at the hip, the left leg below the knee, and the right arm below the elbow in a 14-month-old child. (*Right*) Same patient, fitted with brace prosthesis at the age of 14 months.

psychological aversion toward the cripple and offsets a prejudice of the employer through the increase in the patient's productivity and working capacity.

But furnishing an amputee with an artificial leg is neither the beginning nor the end of the rehabilitation process. The whole philosophy of rehabilitation can be summed up in the comparison between the older method of managing the amputee's problems and the modern method of doing so.

Under the old scheme, the surgeon would concern himself with the surgery alone, the limb-maker would concern himself with the prosthesis alone, but not enough attention was paid to all the problems of the amputee

In order to ascertain what some of these problems were, what the basic needs of the amputee consist of, I conducted a large clinic which men, women and children with amputations of all types attended.

Case 1. Among the many patients that attended this clinic, the first was an 18-year-old boy who had lost his leg when he was 4 years of age. He came to the clinic with his mother, and he did not have an artificial leg As he walked down the aisle with his crutches, I turned to his mother and inquired, "Where is this boy's artificial leg?"

She said, "He never had any."

I asked, "Why not?"

She replied, "Because the doctors and the neighbors said I should wait until he grew up."

Fourteen years had been wasted, 14 years during which time this boy was practically condemned as a cripple, retarded mentally, socially, vocationally and in every other way. But more important, he had lost 14 valuable years of practice. Had he secured his limb when he was 4 years of age, he would have had 14 years in which he would have become artistically adept in the use of his prosthetic appliance.

From this experience we learned that artificial limbs should be applied as early as possible. Children who are born without limbs are fitted when the patient is 10 or 11 months of age in the case of the lower extremity. In the case of the upper extremity, a prosthesis is applied between 2½ and 3 years of age.

Case 2. The second case was that of an industrial accident in which a young man had lost his leg above the knee. He had been furnished with a very fine modern artificial appliance. However, on removing his prosthesis and examining his stump, I found that he was wearing not 1 stump sock between the socket of the artificial limb and the stump of the amputation, but 12 stump socks. His stump began to shrink immediately after the operation. There was no one to give him the necessary advice and counsel as to what to do, so as the leg shrank, he continued to apply more and more stump socks.

Case 3. The third case was an Army Major with a below-knee amputation. He was suffering from a chronic draining ulcer on the stump. The limb-maker, in this instance, must have spent more than $1,500 in time, labor and materials attempting to adjust the socket of the artificial leg to this ulcer. When I saw the patient, I took a roentgenogram of the stump and found that he had a sequestrum. It was a very simple matter to remove this piece of dead bone, after which the stump healed, and an artificial leg was applied.

Now what does this all mean? It means that the old system is a single-phase approach, where the surgeon is interested in his pet operation, the limb-maker is interested in his profit, the inventor is interested in his pipe dream, and no one is interested in the patient. Rehabilitation is a multiphase system, in which the total needs of the individual are respected as well as his specific needs. In approaching it from this point of view, we realize that we cannot begin with the artificial limb, sometimes not even with the amputation, but we must begin, at times, even before the amputation.

PSYCHOLOGICAL PREPARATION

We must begin with what might be called psychological preparation or orientation. Do you have any idea of what goes through the mind of a person who is about to lose his leg or has lost his leg? You will use the word "shock" to describe the emotional reaction to such an experience. Yes, the patient does have surgical shock, but he has another type of shock, one that can be characterized only by the word "grief," one that evokes the same feeling of deep loss that is experienced when an individual loses a member of his family, when he goes into mourning and has a deep sense of depression. Of course, the amputee has lost a part of his body. He now has a new look, an impaired look, a defective look, a crippled look, a handicapped look. But in addition to this shock and grief, he has many apprehensions. "What's going to happen to me? Will I ever be able to walk again? Will I ever be able to work again? What will my family think? What will my boss think?" These and many other questions are posed by this new experience, and the doctor, the nurse and all the paramedical personnel, as rehabilitation officers, must respond to them. In this capacity it is our function, our responsibility, our duty to reassure the patient, not only by patting him on the shoulder but also by helping him to understand his future possibilities, the process of rehabilitation and the necessity for giving him insight so that he can be an active member of the rehabilitation team which will help to restore him to normal.[12]

Patting him on the back and telling him that he will be all right is not enough. Concrete measures must be employed to reassure him. This can be done only by having him see other individuals who have lost limbs and how they have made their respective





FIG. 2. (*Left*) Total amelia with left shoulder complex, including scapula absence. (*Right*) Same patient, fitted with stubbies and single-arm prosthesis.

adjustments. He must be shown the various steps in his future rehabilitation. It is best for another amputee with whom he has rapport to carry out this part of the first step of rehabilitation.

In addition to apprehension and shock, parents of children who are born without limbs are frequently overwhelmed by a sense of guilt. One mother of a child who was born[5,6] without arms and without legs, nothing but a head and a torso, came to me and asked me three questions. She said, "Doctor, was this my fault? What sin did I commit to make me a victim of this horrible catastrophe?" I reassured her.

I said, "This is not your fault. This is a biologic accident, a freak of nature, just as much an accident as walking across the street and being struck by an automobile." She was partially reassured.



FIG. 3. (*Left*) Congenital absence of both lower extremities and both upper extremities. (*Right*) Same patient, fitted with leg and arm prostheses, ambulating with crutches

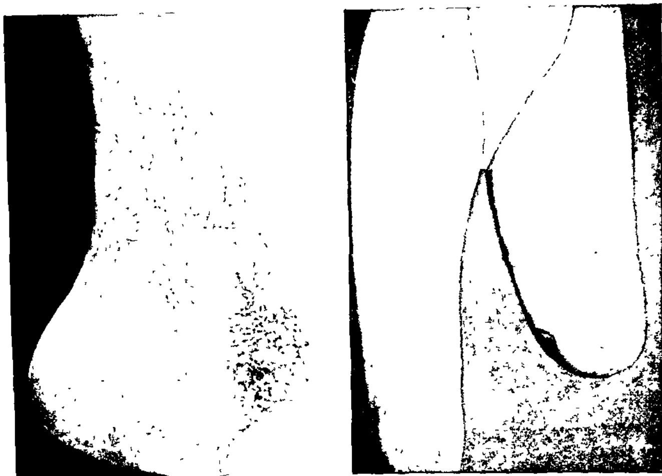


FIG 4. (*Left*) Poor partial foot amputation, necessitating later revision into Syme's. (*Right*) Excellent amputation at classic site at the junction of the lower and middle third.

Secondly, she asked me, "What can I do for my child?" I threw up my hands.

I said, "I don't know. I have been in this work for 30 years and I have never seen such a case; but," I said, "I am learning. We are all learning from our experiences with other severely disabled cases. Here, for example, is a man who is paralyzed from his waist down, and both legs are amputated above his knees. Now watch what he does; watch what rehabilitation has done for him." And she saw this man, without any assistance, get up from the floor into his own artificial legs, stand up without assistance on two crutches and walk up and down a short flight of stairs.

I said to the mother, "We will learn from him how to meet the needs of your child."

Then she said, "What shall I do about arms?" We were able to demonstrate to her 2 cases, both of whom had a disarticulation at the shoulder, and how we had utilized the pectoralis muscle through cineplasty to activate the terminal device or prosthetic appliance.

Then she had a third question, "Doctor, shall I have any more children?"

I replied, "Theoretically, if you were to have 8 children, 1 would be born with a physical defect."

Just then one of the other mothers in the clinic spoke up and said, "Doctor, I think I can answer that question better than you can."

I *said*, "*Why, what do you mean?*"

"Well," she said, "I was faced with that problem 15 years ago when my daughter was born without a hand. I have had 3 chil-



FIG. 5. (*Left*) Severe flexion contracture, necessitating reamputation into Stokes-Gritti or mid-thigh. (*Right*) Same patient. Flexion contracture amenable to correction by stretching and other physical-therapy measures.

dren since who are perfectly all right, and I'll say to that mother, you go ahead and have children." The mother of the child did have a second child, a perfectly normal one.

These are the apprehensions, the qualms and the guilt feelings with which we must deal in the first step of rehabilitation. Only by full explanation and full understanding and by developing insight in the patient can we prepare him psychologically for the rigorous road ahead.[9]

SURGERY

Surgery of amputations has had a long history, dating back to prehistoric times Amputations for gangrene were described by Hippocrates.

Until the 16th century, the mortality rate from amputations was exceedingly high. Bleeding was controlled primarily by cautery. Not until the advent of Ambroïse Paré in the 16th century was the ligation of vessels introduced along with the tourniquet. In the 17th century, amputations were practiced regularly, chiefly for injuries sustained in the war.

In the Napoleonic wars large numbers of wounded soldiers needed amputations, and the name of Larrey dominates this period. He performed a large number of amputations and most of his patients survived. At about the same time the work of the English military surgeon George Guthrie became prominent.[14]

The advent of anesthesia, in 1846, was an important milestone, allowing the surgeon

more time to provide better flaps, and also relieving the patient of the horror of the pain associated with the amputation.[10]

Today, with the advent of antibiotics and the use of whole blood, the surgery of amputations has been simplified. Out of the welter of procedures, we have learned that there are 5 standard procedures which are adequate for most cases, namely, the Syme's amputation at the ankle, the below-knee stump, the knee disarticulation, the classic site of amputation at the junction of the distal and the middle thirds, the Stokes-Gritti amputation at the knee. Hemipelvectomy in the case of malignancy and hip disarticulation are added procedures used when necessary.[11]

AMPUTATION STUMP

The majority of stumps are those which have resulted from amputations due to disease or injury. The stumps may be designed for end-bearing, side-bearing or proximal-bearing.

In the care of the amputation stump, it should be realized that the stump is a pathologic organ. It frequently shrinks. Often, it is accompanied by contractures of the adjacent joints, and unless these contractures are prevented or corrected and unless shrinking is adequate, considerable difficulty will be encountered in the application of an artificial limb.

Frequently, middle-aged people are the ones who complain bitterly concerning the fit of the artificial leg. This is due to the fact that prolonged sitting or improper posture has produced flexion contractures. Therefore, it is necessary that immediately after amputation proper posture of the amputation stump be carried out. All pillows and sandbags should be removed. The patient should be placed on his face. Exercises should be carried out to provide full range of motion of the joints adjacent to the amputation. Once the contracture has occurred, a systematic stretching must be carried out to overcome it.

In order to expedite the shrinking of the stump, the application of elastic bandages should be used to bring the stump down to a more or less stable condition. Without this preliminary shrinking, the application of an artificial limb becomes difficult, since rapid shrinking takes place with a new prosthesis, and in a very short time it does not fit.

Systematic preprosthetic exercises of the amputated leg are necessary, preliminary to the fitting of an artificial limb. More important still are the exercises which fall under the heading "general conditioning." Not only is it necessary to reinstate the integrative reflexes that have been impaired by the loss of the limb, but it is also important to exercise the muscles far removed from the amputation site, since the orchestra of muscular ac-

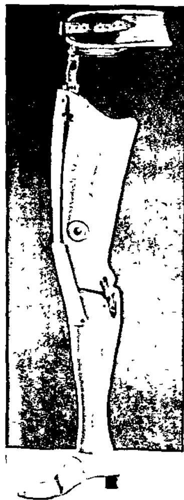


Fig. 6. Standard above-knee prosthesis with pelvic band and suction.



FIG. 7. (*Left*) High bilateral above-knee amputation in a girl of 15. (*Center*) Same patient with bilateral above-knee suction prostheses with Silesian belt and (*right*) posterior view.

tion requires participation by the whole group. For example, bilateral above-knee amputees will have considerable difficulty in learning to balance themselves, unless a systematic program of abdominal muscle exercise is carried out During the first year, the stump is "green," and until it is "seasoned" one must anticipate a substantial amount of attention and services. The patient should be alerted to these facts. By preventing contractures, by preprosthetic exercises and early shrinking, the problems can be minimized.[3]

THE ARTIFICIAL LIMB

No attempt was made to develop artificial limbs until the 19th century, except by men like Ambroise Paré. Prior to that time, peg legs were the usual type of prosthesis.

The Napoleonic wars stimulated some development of artificial limbs, but not to a great degree

In the United States, the great stimulus toward artificial-limb manufacturing came from our Civil War. The large number of amputations (more than 10,000 on the Union side) was the inspiration for American ingenuity in mechanics to create modern artificial limbs.

World War I was a similar stimulus for the development of artificial limbs, more particularly in Europe. At Queen Mary's Hospital in Roehampton more than 41,000 patients were fitted for limbs for amputations suffered as a result of World War I.[4,6]

World War II provided another impetus for the development of artificial limbs. The Prosthetics Research Board undertook this development and provided a comprehensive plan of attack which has furnished us with modern advances in the manufacture, the servicing and the fitting of limbs.

The amputee will frequently ask, "Doctor, what kind of leg will I get? Will it be made out of metal, fiber, plastic, leather?" The physician must explain that the first consideration is not the design, the materials or the weight, but the fit If the leg does not fit, it is useless.[5]

In this short discussion on the rehabilitation of the amputee, detailed considerations of the different types of lower extremity prosthesis—conventional and special—can-

not be included. One word, however, about suction prosthesis. Though originally conceived by an American in 1865, the German manufacturers developed it with great success in World War II. After World War II, we adopted it slowly, and it is becoming more and more a standard type of prosthesis. In the beginning, the contraindications were great; now, they are fewer. However, since the stump may increase in size rather than shrink, the patient must be made aware of the need for more servicing in the first year.

As a result of the effort of the Prosthetics Research Board, short-term and long-term courses in limb-fitting and limb construction have been established, providing limb fitters, as well as all the paramedical personnel interested in the rehabilitation of the amputee, an opportunity to learn modern methods in limb prescription and limb manufacture.[15]

In the course of this program, personnel are taught to prescribe the proper prosthesis. While 90 days is too short a period of time for a physician to acquire all the necessary information on the basis of which he can prescribe a prosthesis; nevertheless, it is a desirable step toward the ultimate goal. However, it is important to realize that the artificial-limb manufacturer and fitter is an individual who is presumed to be a craftsman of experience and wisdom. Limb-fitting and limb manufacture is an art which cannot be acquired from a book in any short course. It requires not only years of experience in the actual fitting but also years of experience in the actual construction of a limb. For this reason I look with a great deal of caution and skepticism on the value of having doctors prescribe limbs unless they have had an intensive course of training and experience in this field. This is a very important matter, since today a large number of public and private agencies are providing the payment for the limbs which later require certification by physicians. Too frequently physicians approve limbs without the full knowledge of the satisfactory fit and alignment of the limb. A checkout system, in which certain points must be examined before the limb is accepted, provides a good theoretic basis, but while all the checkout points may be satisfied in the mind of the certifying physician, the limb still may not provide the comfort and the efficiency demanded by the patient. A note of caution: this present system is a good beginning, but not enough to qualify a physician to certify the adequacy of a prosthesis.

My own attitude toward this whole situation is as follows: In my own case, having been associated with the manufacture and the fitting of limbs for 40 years, I still feel hesitant in prescribing a limb without the limb-maker or limb-fitter being present. In my opinion, the prescription of the limb and the certification of its satisfactory fit is a joint responsibility of physician and limb-maker.[8]

The limb-fitter and limb-maker has come a long way from those early days when he rarely trained; where he may have been an amputee who became a company salesman with limited background and scanty understanding of his professional as well as ethical responsibility.

More than 300 limb-makers in this country are now banded together in an association, the OALMA. This association took the initiative in creating a certifying board composed of both limb-makers and orthopaedic surgeons. This board was established in 1947 and has continued to act in a supervising fashion analogous to the boards in the surgical specialties. Out of this control and this understanding on the part of the limb-makers have come better training and better professional control of the limb-making art and industry. It is for that reason that we, as physicians, should understand and respect these limb-makers for their professional capabilities. It is a mistake for physicians or orthopaedic surgeons to attempt to rectify changes in artificial limbs either without a

long experience of their own or without the consultation of the limb-maker.

TRAINING

Finally, the fifth step in the rehabilitation process is that of training. If I were to ask an individual to go into a music store to buy a violin and to go out immediately and play Bach and Beethoven, one would characterize that act as silly and unnatural; but it is equally unnatural to expect an individual to apply an artificial leg and immediately go out and use it. Without the training in the use of that artificial limb, the individual will always be an imperfect walker and user of the artificial limb.

The first step in the training process is not to teach the individual to walk but to teach him to balance himself. Walking is nothing more or less than losing one's balance and regaining it. Therefore, the patient must be taught standing balance. Each day, systematic daily intensive training in balance is carried out. After he has learned to balance himself, then it is time for him to learn to walk.[1,2]

Then he is taught to walk not only on the level but on irregular surfaces—up and down ramps, up and down stairs. In that way, he soon acquires the ability to carry on all the normal routine pursuits of life in the field of ambulation and travel.

SUMMARY

We have compared the older type of management of the amputee, which we have referred to as a 1-dimensional system, with a modern rehabilitation concept which views the responsibility of the surgeon as 5-fold. We have described the need for psychological preparation, for adequate surgery, for aftercare of the stump, for the prescription of the prosthesis, and finally, for training the amputee in the use of his artificial limb. We submit that this modern multiphase program more adequately meets the needs of the amputee than the old-fashioned single-phase approach. Rehabilitation is more than the rebuilding of an individual's residual capacities. It represents a fierce belief in our individual responsibility for what happens to our fellow man.

THE UPPER-EXTREMITY AMPUTEE

GENERAL CONSIDERATIONS

The arm amputee is faced by a triple threat. First of all, there are the obvious physical defects restricting and diminishing his range of activities not only for use in industrial work but also for the thousand and one pursuits of life that make for satisfactory social living. Secondly, there is the serious emotional disturbance associated with the loss of a member and the poignant knowledge that he is no longer like other people. Finally, there is a serious threat that he has to face in the attitude of society at large.

To these three serious problems the amputee makes a variable adjustment. Some of the individuals will compensate for their difficulties and achieve unusual success. Others, overwhelmed by the seriousness of the nature of their disability, will soon slough off to become a burden to their families or the local bounty of friends and neighbors. However, the majority make favorable adjustments as they struggle valiantly and patiently until the intangibles of life tip the balance in their favor.

The function of the lower extremity, namely, weight-bearing and locomotion, can easily be reproduced synthetically. The function of the arm, with its manifold functions as an extension of the human brain, cannot be duplicated. It can only be imitated, and it is a poor imitation at best. It is important to understand these limitations and to impart to the patient realistically the limitations of all prostheses. Too many are disappointed because of the failure to measure up to expectations. One of the most serious defects is the loss of the sensation of the hand. In our preoccupation *with the prehensile* or

tool-like action of the hand, we fail to appreciate the function of the hand as a sense organ. It is not only a tool; it is also an eye of the blind and the tongue of the mute. The rehabilitation described in the section on amputations of the lower extremity applies to the individual who has lost his upper extremity. These steps consist of (1) psychological preparation, (2) proper surgery, (3) care of the stump, (4) adequate prosthesis and (5) adequate training.

PSYCHOLOGICAL PREPARATION

Before proceeding with the patient's rehabilitation, an appraisal or inventory should be made of the patient's total personality needs. We fit the lower extremity prosthesis to the patient's stump, but we fit the upper extremity prosthesis to the patient's personality. By this we do not mean the patient's "Hollywood" glamor. What we do mean is that we take into consideration the patient's total needs as an individual. Since personalities differ, it would be a mistake to recommend one type of procedure or one type of prosthesis. What is required is an array of devices or of measures to meet the specific needs of the individual. The farmer in a specialized community requires considerations that the doctor in a large city does not require. The salesman and the truckdriver coming from different social milieus also will have different requirements. It is important to analyze these requirements and select from the armamentarium of procedures those which will meet the special requirements of the individual [3,4]

Of great importance, as part of the psychological preparation, is indication to the patient of the limitations of all prostheses. Unless this is done, the patient will expect too much from his prosthesis and be inclined to give little of himself. The amputee in his early adjustment may fail to realize that his own slow progress is the result of the limitations inherent in all prostheses. He attributes his own shortcomings to the prosthesis, and he soon discards it. I have met many individuals with empty sleeves and I have approached them to inquire whether or not they ever had worn an artificial arm. The majority have worn an artificial arm but have discarded it because of a "dead hand." No one had told them about the limitations of prostheses, and they had expected normal use of the hand.

Another decision the rehabilitationist must make is which of the two essential functions of a prosthesis to stress—utility or appearance. So strong is the power of social prejudice that the esthetic appearance must be given very serious thought in assisting the amputee in his adjustment. A decision between the utility hook and a mechanical hand will be determined in large measure by the more favorable social response that the artificial hand will produce. However, the greatest value of the prosthesis lies in its power to contribute to the patient's total range of activities.

There is still considerable controversy as to which consideration should receive greater emphasis, utility or appearance. The advocates of the hook appliances believe that it is best for the patient's emotional life to accept reality by wearing that which will be the most useful. Further, it is claimed that the use of the mechanical hand only continues the masquerade of normality and that its very shortcomings emphasize the fraud. However, there is a middle road—that of exercising critical judgment. The choice of the prosthesis is made after the factors of utility and appearance are weighed in the light of the patient's own personality and the social and industrial problems he must face.

The intricacies and the ramifications of the function of the hand are such that only a few of its fundamental uses can be duplicated. All of these matters must be discussed with the patient seriously and realistically. No quick judgments or prescriptions must be made without giving the patient an opportunity to digest the information. Furthermore, he must be given every opportu-



FIG. 8. Double-forearm amputee equipped with cineplastic prosthetic appliances with complete hand operated and controlled by cineplastic motors. (Kessler & Gelb: Plast. Reconstruct. Surg. 13:10)

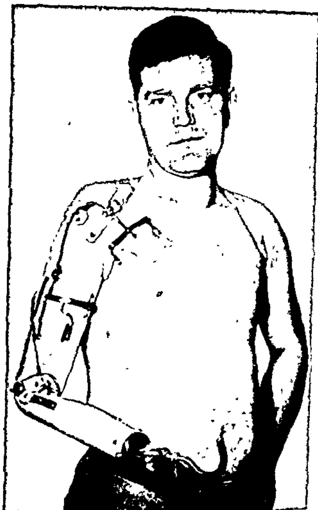


FIG. 9. Pectoral cineplasty in which the terminal device is operated by a shoulder control cable while the pectoral motor controls the elbow lock. (Kessler, H. H.: *Cineplasty*, Springfield, Ill., Thomas)

nity to meet with other amputees; to visit several limb shops until he is thoroughly informed. After several interviews, we are in a better position to come to a decision with the amputee.

SURGERY

The primary surgery in amputations in the upper extremity should follow, more or less, a conservative course. The preservation of all tissues is essential, primarily to preserve sensation. This, of course, refers to fingers. There are instances where the preservation of an excessive amount of tissue may interfere with proper fitting of artificial limbs. This matter is still controversial as, for example, a wrist disarticulation, done in a woman; and where a functional prosthesis appears to be too long. However, it is safe to say that in the primary surgery of amputation stumps, the principle of the conservation of tissues should prevail.

Following the primary amputation, secondary surgical procedures may be required. The Krukenberg amputation, in which the forearm is split to construct two digits, which, by their opposition, provide prehension, is an operation well thought of in Russia, Germany and Finland. It has not readily received acceptance in the United States, although a number of these procedures have been done, particularly in cases of blind double-arm amputees.

CINEPLASTY

The cineplastic operation was introduced into the United States in 1932 by myself but has found only limited acceptance. It was rediscovered in World War II following



FIG. 10 (*Top, left*) Congenital absence of both arms (*Top, center*) Bilateral pectoral cineplasty performed on rudimentary pectoralis. (*Top, right*) Minor muscles. (*Bottom*) Equipped with bilateral arms with terminal split utility hooks operated by the pectoral motors; elbow control operated by scapula movement. (Kessler, H. H.: *Proceedings of Kessler Institute for Rehabilitation, New Jersey* 1:28)



Fig. 11. Use of the utility hook for a partial hand amputation.

the findings of a special commission of the National Research Council, which visited Germany and learned the value of this procedure. Today, a number of war amputees have experienced the value of this procedure and are wearing artificial limbs of the conventional type cineplastically controlled. Unfortunately, in spite of all the money spent on the development of artificial limbs following the war, little to nothing was done in the development of a special artificial limb for cineplastic operations. The operation was never intended to provide an extensive amount of power in activating such a heavy limb as the standard conventional arm. Special limbs have been constructed but have not entirely met the requirements of the individual. Shrinking of the stump of the upper extremity is not carried out with the same degree of intensity as in the lower extremity. Rarely is there the edema and the volume which require shrinking, whereas an excessive amount of bandaging frequently interferes with the normal muscle action. Special care of cineplastic muscle motors and Krukenberg stumps is required in the postoperative phase and in the training phase.[1,2,6,10]

THE PROSTHESIS

The selection and the prescription of the prosthesis requires careful critical and psychological analysis. Not only are there personality differences but there are also differences so far as the extent and the character of the amputation are concerned. For example, the single arm amputee is rarely

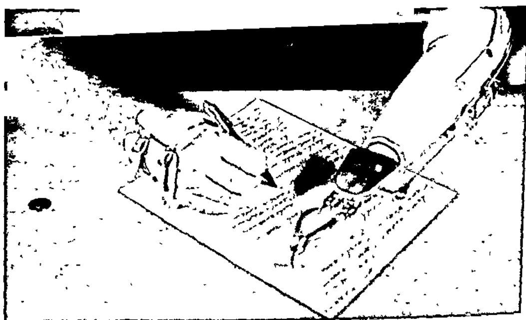


Fig. 12. APRL hook used as standard prosthesis controlled by shoulder cable.

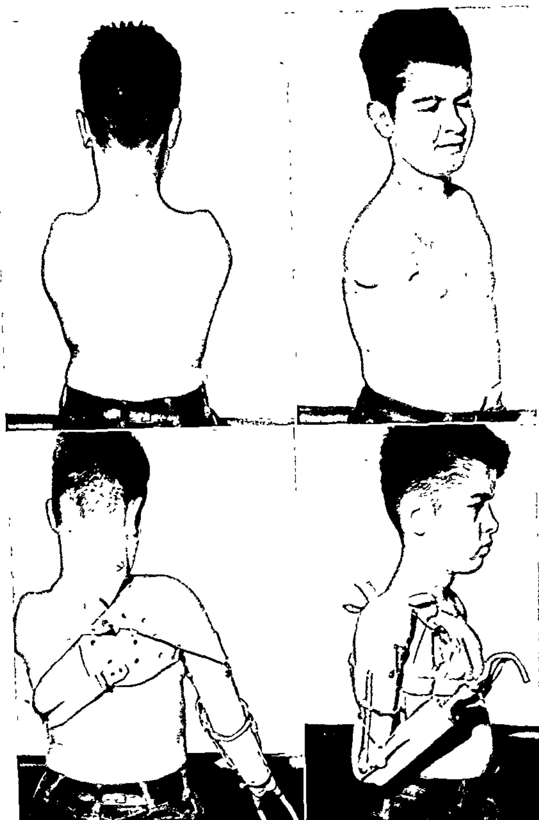


FIG. 13. Bilateral absence of both upper extremities with single pectoral cineplasty operating terminal device with elbow operated by scapular action. (Kessler & Gelb: Plast. Reconstruct. Surg. 13:10)



Fig 14. Krukenberg operation performed on blind double-arm amputee. Cineplasty performed on the left side. Patient in occupational therapy department developing tactile and proprioceptive functions on improvised weaving apparatus. (Kessler, H H.· Proceedings of Kessler Institute for Rehabilitation, New Jersey 1:28)

severely disabled. He uses his remaining arm for carrying out the routine pursuits of life, which he does very effectively after a short period of adaptation and adjustment. For that reason many of these individuals do not wear artificial limbs. The story of Barbara is a case in point.

Case Report. Barbara was 16 years of age when she was sent to me by the New Jersey Rehabilitation Commission She was born without her left arm. The amputation occurred about 2 inches below the cubital flexor crease She was disinclined to wear an artificial arm, since all her life she carried out the routine pursuits of life without any difficulty. Her relationship with boys was not impaired in any way, since she did not feel selfconscious and did not experience the effects of prejudice, so characteristic in many amputees. She had planned to become a librarian and spent 4 years preparing herself, graduating with high honors. At the end of that time, she returned to me in tears. It seems that after graduation she had sought work in several libraries, and as she explained it to me, she said, "Doctor, I did not go from factory to factory where I would expect people with a little bit less understanding to show less compassion, but I went from library to library, nice people, intelligent people, cultured people, and I was turned down in every place because I had one arm." She did not realize the intense social prejudice which would interfere with her ability to procure a job. Therefore, she insisted on having an arm because of the social and cosmetic implications.

While wearing a prosthesis may be optional for a one-armed amputee, for the double-arm amputee it is indispensable and imperative that he be fitted with an arm. While a few double-arm amputees get along without prostheses, the majority require prostheses. There is a wide array of devices to choose from. Peculiar enough, the split utility hook, which has become the standard prosthesis in America is not accepted in Russia and has been accepted only recently to a slight extent in Germany. In England it has been replaced in a large measure by the so-called "work arm" Furthermore, at the Naval Hospital in Mare Island, where a large number of arm amputees were rehabilitated and given prostheses, generally with the standard type of split utility hook, we frequently found that the patients made personal alterations in the prosthesis in order to meet their special needs. Some of the patients altered the shape of the hook making it straighter or more curved. Some added more elastic bands. Others replaced the elastic bands with metal springs Still others incorporated an outrigger for their special needs in driving an automobile. In other words, there was no standard device. Each device had to be fitted to the patient's special needs.

The double-arm blind amputee is a different type of arm amputee from either the single-arm or the double-arm amputee. The blind double-arm amputee demands sensation or contact with the outside world. This is even more imperative than pure prehension. Therefore, it would be a mistake to fit a blind man with a double-forearm amputation with two split utility hooks. One amputation stump must be kept free to be used as an antenna. A great many variations have been carried out, such as providing one arm with a split utility hook or an Army Prosthetic Research Laboratory (APRL) hand while the other hand is left intact, or a Krukenberg amputation is performed. With the Krukenberg operation, the patient retains his sensation, but he also has a measure of prehension which helps him to carry out some of his natural grasping functions.[5,7,8]

TRAINING

As with the lower extremity amputee, the upper extremity amputee requires considerable training. The patient has lost not only part of his arm but also part of his skills. The arm and the hand constitute a sense organ. It is an extension of the patient's brain, and for that reason the reeducation and the retraining of many of the integrative and proprioceptive reflexes becomes an important part of the rehabilitation program. It may start as soon as the bed patient is ready for activity. One of the first things he has to learn is writing. This ability is closely related to the larger function of handedness. The right-handed man who loses his left hand suffers no disability in the performance of unilateral tasks; he has lost only the ability to perform bilateral tasks. This will be partially restored by his prosthesis. However, it will still be necessary for him to develop through compensatory activity increased dexterity with his remaining hand. This provides a safety factor which slowly permits him, with increasing facility, to accomplish some of the tasks which originally required the use of both hands. The lighting of a match, the tying of shoe laces, the acts of dressing and



FIG. 15. (*Left*) Bilateral high double-arm traumatic amputation utilizing Heidelberg pneumatic prosthesis. (*Center*) Side view showing 2 CO_2 cylinders. (*Right*) Six movements are carried out by the pneumatic prosthesis; elbow flexion and extension, pronation and supination at the wrist, opening and closing of hand. Shoulder abduction is carried out actively by the remaining stump.

similar performances are soon learned by means of ingenious shortcuts and the dexterous use of the fingers in the remaining hand. The development of this safety factor is aided by occupational therapy designed to increase the strength and the dexterity of all fingers of the remaining hand. Fly-tying, finger-painting, clay-modeling and typing are activities which are used to develop this function. By encouraging compensatory activity before prosthesis, we are deliberately building habit patterns, which must be modified later by the added use of a prosthesis.

The right-handed person who loses his right hand, and the left-handed person who has lost his left hand have more serious adjustments to make. They must now adjust the remaining hand to the demands of the world in which they live. This is a "right-handed" world. The question that is frequently raised is "Shall we teach him to become left-handed with his sound remaining arm or shall we retain the psychomotor patterns in the use of his prosthesis?" Theoretically, the retention of all these habit patterns is desirable. However, the daily demands of living require that the remaining arm immediately fulfill some of its prehensile duties. This it does almost automatically for gross prehensile movements. However, the requirements of fine and dexterous movements are other matters.

Handedness is a complex and highly integrated function based on and associated with binocular vision, the development of speech, the development of reading and the dominance of one cerebral hemisphere. About 90 per cent of the population is right-handed, and the left cerebral hemisphere is dominant in that group However, this dominance is only relative, since all the functions associated with manual skill are not confined to one hemisphere No learned motor skill, for example, can be practiced without certain associated functions taking place prior to the carrying out of any complex motor act. There must first be a psychic elaboration of ideas or apraxia. Even though the normal person knows how to do a thing quickly and almost automatically when requested, nevertheless in the early stages of learning to perform that act, the performance was already planned in the opposite precentral and supramarginal gyri. Inability to perform in response to a command is referred to as apraxia and is a symptom of injury to the sensory-motor elaboration areas of the cortex.

The question of dominance has been somewhat overemphasized. There is no 100 per cent use of one hand over the other. Most persons are largely right-handed or left-handed, but 10 to 15 per cent of the population are ambidextrous. They have no clear dominance and thus lack leadership in initiation of speech, writing and reading.

From a practical point of view, however, the amputee may experiment with both hands in learning to write. He soon sees for himself by the character of his penmanship which is the proper hand to use — sound hand or prosthesis. Regardless of his choice, he is taught to typewrite with his one remaining hand according to a definite system. This and the other activities named above are used to develop his finger dexterity. For the man who has lost a dominant hand, the development of compensation is a much slower and more tedious process than for the man who has lost his secondary arm. For him it is particularly important that training be started early.

EQUIPMENT

Special devices can be attached to the amputation stump for carrying out some of these activities.

In high double-arm amputations, where it is not feasible to apply even adapted equipment, the teeth of the patient may be used in carrying out some of his communication needs. For example, in a recent case of electrocution where bilateral amputations had to be done close to the shoulder, the patient was provided with a paint brush with which he learned to paint the alphabet. Later

he adapted his artistic ability to the painting of various objects.

SUMMARY

Thirteen years after the end of World War II every man, woman and child who has suffered an amputation from injury, disease or congenital deformity can be fitted and rehabilitated with modern prosthetic appliances. This American contribution represents a major improvement in the situation. Formerly, heavy ugly complicated arms were rejected by the amputee or found to be so impractical that soon they were left on the shelf.

These substantial changes resulted from many factors. For the first time, a national agency was established to carry out research in the field. New light-weight materials were developed. Beautiful lifelike, cosmetic gloves with natural fingers and hands replaced the old ugly black-gloved artificial hand. A general acceptance of the split utility hook as a practical functional device constituted an important factor.

Of greatest importance was the concept of providing amputee rehabilitation as a complete service, instead of seeking a will-o'-the-wisp in a universal device that would meet every need and every personality. It was soon discovered that the arm amputee must be treated differently from the leg amputee. While it is a relatively simple matter to duplicate the lost function of weight-bearing and ambulation, the function of the hand as a tool and as a sense organ cannot be achieved. Its function as a tool can be imitated but not duplicated. But in spite of these limitations, useful applications can be achieved, especially if we remember this most important axiom: namely, not to fit the prosthetic device to the patient's stump but to fit it to his personality. We must analyze what special needs have been lost as a result of the amputation and how far it is practical and possible to replace them partially or completely.

It can readily be seen that to achieve this objective there is no one universal "miracle" arm that can fulfill all requirements. What is required is a large armamentarium or array of devices from which we can select one that will meet the special needs of the patient. Fortunately, many devices already exist; some have been renewed and others are new.

The standard split utility hook has become the workhorse as a functional device. Even children and women have accepted this device despite the unpleasant appearance. Where the latter is an important factor, plastic reproduction of the hand or gloves mitigate the unpleasant reaction or rejection by strangers or associates.

In addition to the standard device, which is also slowly receiving acceptance in Europe, two additional methods help the surgeon to solve the special needs of the amputee. One of these is cineplasty. By this method, the muscles left in the amputation stump are utilized as a source of power to move hands or hooks. Unfortunately, a truly cineplastic device has not been developed, and we have been forced to rely on conventional arms and hooks with loads applied to the muscle motors beyond their competence.

Heidelberg Arm. The newest device that has been developed is the Heidelberg pneumatic arm.[9] The source of power to activate the hand, the wrist or the elbow is a cylinder of compressed carbon dioxide. Valves, regulating the flow of gas to the specific joint, provide smooth physiologic action, close to normal. This arm is still in the developmental stage but promises much, especially for the short upper-arm amputee or the double-arm amputation.

From this brief review it can be seen that a picture of hope can be presented to the arm amputee, not in the form of human replacement for his lost member, but in useful restoration of his lost function and appearance. To achieve this aim requires the mutual co-operation of surgeon, limb-maker, physiotherapist and all those dedicated to the rehabilitation of the handicapped.[11]

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Rehabilitation post Amputation de Extremitates Inferior

Le rehabilitation del individuo con amputate extremitate inferior es un servicio comprehensive que include le sequente phases:

1. Preparation pyschologic del patiente.
2. Chirurgia adequate.
3. Cura post-operatori del trunco.
4. Selection, prescription, e adjustation del prosthese.
5. Trainamento del individuo in le uso del apparato prosthetic

Le major progressos del decennio passate in le manipulation del problemas de amputatos ha resultate ab iste nove philosophia a tres dimensiones per contrasto con le previe concepto unidimensional de responsabilitates independente.

Il es solmente per le collaboration del chirurgo, del prosthetista, del therapeuta physic, del therapeuta occupational, del consiliero in questiones de profession, e del communitate que le requirimentos e le speros del amputato pote esser satisfacite de maniera adequate.

Rehabilitation post Amputation de Extremitates Superior

Summario in Interlingua

Le rehabilitation del individuo con amputate extremitate superior observa le mesme principios general como le rehabilitation del individuo con amputate extremitate inferior. Illo include le sequente phases:

1. Preparation psychologic del patiente.
2. Chirurgia adequate.
3. Cura post-operatori del trunco.
4. Selection, prescription e adjustation del prosthese.
5. Trainamento del individuo in le uso del apparato prosthetic.

Le principios del tractamento de amputationes de extremitate superior differe del principios in le tractamento de amputationes de extremitate inferior in tanto que protheses inferior es adjustate al trunco del extremitate amputate durante que prostheses superior debe esser adjustate al personalitate total del patiente e a su requirimentos individual.

A causa de iste situation, un vaste armamentario de mesuras e dispositivos es requirite ab le qual on pote seliger le prosthese specific pro omne caso individual.

Le preparation psychologic del patiente con amputation de extremitate superior es ancora plus importante que illo del patiente con amputate extremitate inferior. Le patiente debe esser informate con respecto al limitationes tanto ben como con respecto al potentialitates de su prosthese. Le utilisation de prostheses cineplastic e pneumatic ha allargate le dominio del possibiltates prosthetic.

10

Rehabilitation of the Amputee*

The Hemiplegic and the Quadriplegic

EARL F. HOERNER, M.D.†

MEETING THE NEEDS OF THE HEMIPLEGIC PATIENT

The management of the hemiplegic patient has been supplemented in recent years with ever-increasing horizons in obtaining rehabilitation goals. This has been found possible through a dynamic approach, and the integrated efforts of all members of the medical and the paramedical professions.

Experiences which have been accumulated in the larger rehabilitation centers and institutions have been disseminated to all members of the medical profession and facilities. This has resulted in definitive methods of treatment. It has also stimulated research and new methods of evaluation.

Since it is reasonable to believe that there never will be enough special rehabilitation facilities and personnel to meet the needs of *hemiplegics (at the present time there are* over 1,000,000 hemiplegics in the United States), emphasis should be placed on procedures which will reduce hospitalization and treatment time and will provide therapeutic processes within the communities in which they live.

TREATMENT

The treatment of patients with cerebral vascular accidents must be considered as biphasic:[13]

1. **Early Care.** The treatment in the immediate period after the onset, which is generally devoted to life-saving and physiologic control measures

2. **Rehabilitation:** (A) prevention of deformity; (B) correction of muscular deterioration through activity; (C) treatment of residual defects. (Fig. 1.)

REHABILITATION

Prevention of Deformity

Postural alignment can, and *should*, be started at once in all hemiplegias, regardless of the pathology, and has been described adequately and repeatedly.[12]

A high-low bed is an aid to the nurse in performing nursing care when it is raised to its high position. In the low position, it is helpful in getting out of bed. This is accomplished best when the feet can be placed firmly on the floor while sitting on the edge of the bed. A shoulder abduction pillow or sandbag placed between the chest and the arm and positioning the shoulder in about 45° abduction and 15° external rotation assists in preventing the frequently observed painful and stiff shoulder. A foot board is used to prevent foot drop. Plaster splints have been used and can be helpful, especially in prevention of contractures. If splints or braces are used, they should be removed frequently, for total immobilization is not conducive to proprioceptive stimulation through controlled movement, which is

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recommended. A sandbag or a pillow placed on the outer side of the foot and the leg will prevent tibial torsion and external rotation of the lower extremity. A hand roll, made of soft material, can be used to maintain the neutral anatomic position of the hand and aid in prevention of deformity. A simple splint, made of plaster of Paris or plastic material (Fig. 2) can also be used for this purpose. Again, this should be removed at frequent intervals for the purpose of proprioceptive stimulation.

During this phase of treatment, range of motion through passive manual manipulation is carried out by a member of the treatment staff. This should be performed daily to all joints of the affected extremities.

As the patient improves, a pulley fastened to the head of the bed on the side of the involved arm and shoulder and supplied with a length of line can be used for passive range of motion of the involved shoulder, with the good extremity supplying traction and motive power.

Activity Program

A knotted rope fastened to the foot of the bed as a single strand or in the form of a rein is helpful in aiding the patient to get into a sitting position through flexion at the hips. Some patients prefer an overhe single-bar trapeze to get into a sitti position.

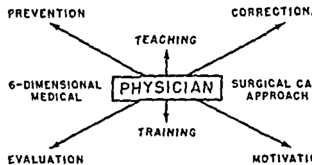


Fig. 1. Cornerstones of biphasic treatment program for hemiplegia.

As soon as the patient's condition pe mits, practice in standing and balanci should be instituted. This upright positi and standing should be with the aid shoes, rather than slippers. If depende edema occurs, an elastic bandage can co trol it without difficulty. Usually, the p tient requires some postural aid; and st tionary supports such as the end of a b a locked walker, or heavy chairs are use in this respect. At times, a tilt board m be necessary to mobilize the patient fro the horizontal bed position to the uprig standing one.

Not infrequently, a rotated leg, an u stable knee or an ankle deformity will r

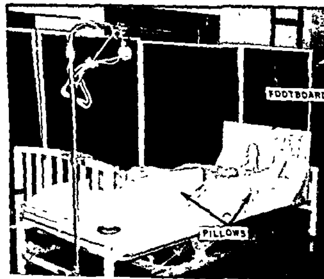




Fig. 2. Bed positioning. (*Left*) Demonstration of footboard and pillows for prevention of leg and foot deformity. (*Right*) Arm and hand positioning with pillows at axilla and under arm and hand.

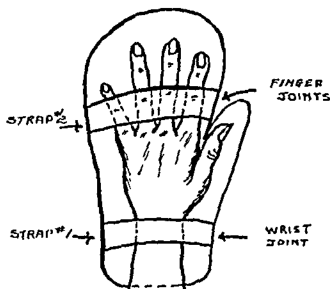


FIG. 3. *Simple night splint.*

of time, it is essential, during the early period of mobilization and activity, to teach the patient to care for his daily needs with his unaffected arm. These include dressing, eating and hygienic procedures. It has been observed that right hemiplegics, who usually present more serious disabilities because of sensory and aphasia complications, can learn to resolve the specific problems of self-care and independence without formal training. This is in contrast with the left hemiplegic who, on clinical examination, presents less of a disability and has extreme difficulty in performing *any* self-care activity without retraining.[4]



FIG. 4. Bed pulley. (*Left*) Lateral view of arm being extended. (*Right*) Full view of extended arm.

quire a stabilizing appliance. Temporary knee supports constructed of plaster of Paris, wood splints wrapped in an Ace bandage, or commercially supplied knee supports can be used in these instances. Temporary twisters, fabricated from elastic webbing or airplane cable can be used to correct an abnormal hip rotation Elastic webbing fastened to the patient's shoe and affixed to the temporary knee support or calf cuff has been found to be useful as an apparatus for training procedures in correcting ankle malposition.

As a return of function in the affected upper extremity cannot usually be expected or prognosticated for a relatively long period



FIG. 5. Knotted rope used for activities of daily living—transfer activities

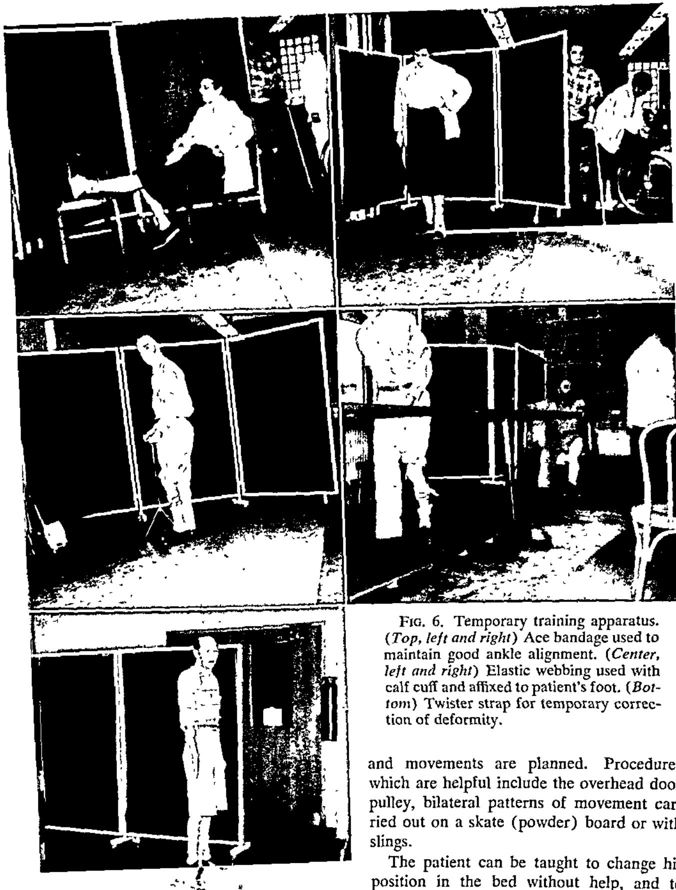


FIG. 6. Temporary training apparatus. (*Top, left and right*) Ace bandage used to maintain good ankle alignment. (*Center, left and right*) Elastic webbing used with calf cuff and affixed to patient's foot. (*Bottom*) Twister strap for temporary correction of deformity.

Activity and mobilization of the affected arm should be started early. Physiologic aids, using the normal arm to assist the involved arm in associated motion patterns and movements are planned. Procedures which are helpful include the overhead door pulley, bilateral patterns of movement carried out on a skate (powder) board or with slings.

The patient can be taught to change his position in the bed without help, and to roll from side to side. With improvement, transfer from the bed to a wheel chair or a standing position is possible. Attention is directed to the fact that the hemiplegic will do better in getting out of bed if he gets in



FIG. 7. Training in one-handed activities of daily living.



FIG. 8. Mechanical sling for mobilization of affected arm.

and out on the side of the good leg. The involved leg will drag along easily. When the patient does transfer activities of this type he can use the foot of his good leg under the heel of the involved extremity to lift it into the proper postural position.

TREATMENT AND ALLEVIATION OF RESIDUAL DEFECTS

If physical restoration is started early, there should be no residual limitation of motion at any of the affected joints.

In evaluating the residual disability, muscle strength, range of motion, activities of daily living, neurologic involvement, general body physical status, complicating factors and interpersonal (the patient's functioning in emotional, intellectual and social spheres) resources must be adequately studied and recorded.

It has been a clinical practice to evaluate muscle strength in patients with upper motor neuron disease in a manner similar to those with lower motor neuron disease such as poliomyelitis. This has led to many difficulties because of the presence of increased muscle tone, abnormal reflex patterns and disturbances in normal patterns of motion. As a result, the attempt to evaluate the hemiplegia, using the poliomyelitis rating scale of grading muscles from 0 to 5, in association with the effect of gravity has met with failure. Recently, there has been developed a new method for thorough evaluation of functioning muscles, taking into consideration these mitigating factors.[1] This method of testing has its physiologic basis in the reflex movements, postural reactions and tonic reflexes.

COMPLICATING FACTORS

Complicating factors which must be taken into consideration in planning the patient's rehabilitation program are as follows:

1. **Posthemiplegia Shoulder Pain.** Persistent pain in the paralyzed shoulder and arm is a frequent complaint. This most often occurs in conjunction with distal extremity spasticity. This pain has been interpreted as being due to: (A) thalamic origin; (B) reflex dystrophy (shoulder-arm) syndrome; (C) trophic changes secondary to

asomotor involvement; (D) specific joint involvement (arthritis); (E) subluxation of he shoulder joint.

The most common cause appears to be downward subluxation of the shoulder oint due to weakness of the musculature upport.[14] This subluxation results in the listention of the shoulder capsule and overtretching of the muscular joint cuff.

The clinical factors that are found on examination are as follows: (A) All paients have complete or almost complete paralysis of the shoulder musculature; (B) he shoulder musculature is flaccid and atrophic; (C) the normal curve of the shoulder is modified by flattening in appearance; (D) the hand and the forearm are edematous; (E) there is pain of the shoulder at rest, with increased pain on passive motion; (F) a separation of 1 cm. or more is present (determined by roentgenogram or palpation) between the glenoid process and the head of the humerus; (G) there is marked tenderness on local pressure over the shoulder joint; (H) the pain is relieved by restoring the normal anatomic position of the shoulder joint.

It is felt that the pull of gravity in conjunction with the weight of the arm is sufficient to stretch the shoulder capsule. This occurs in both the sitting and standing positions. This capsule stretch leads to subluxation and overstretching of the muscles surrounding the shoulder. The hemiplegic patient attempts to correct this complicating problem by maintaining the arm in adduction. With the passage of time, maintaining the position of adduction can lead to contracture with resulting further pain and complication.

Therapy consists of adequate support of the shoulder joint by means of a sling and proper posturing at night. This counteracts the pull of gravity and results in relief of the symptomatology. Adduction contracture must be prevented by passive motion of the shoulder, with proper position of the humeral head in the glenoid fossae. Attempts at improving the muscle tone of the shoulder area through electric stimulation have not proved to be successful. As, or if, active contractibility of the shoulder muscles occurs, neuromuscular patterns with the use of a skate board for elimination of gravity have been beneficial. Relief of the symptoms of shoulder pain occurs with improved muscle strength and control in the shoulder area.

2. Contractures. The most common contractures that occur are those of the shoulder, the hip and the knee joints.[7] Although these complications are uncommon if definitive treatment is provided during the early care of the patient, they do occur, and since they are preventable, they merit careful attention. The preventive measures have been outlined under the sections "Prevention of Deformity" and "Activity Program."

In the rehabilitation of the patient with hemiplegia, the presence of a knee contracture of more than 10° makes ambulation difficult, if not impossible. The duration of immobility of a joint necessary to develop a fixed contracture is not known. One experimental claim has been that contractures become evident after 2 or 3 days of immobilization; however, patients have been observed who for years have been maintained in positions of muscle shortening *without* developing a fixed deformity. Factors other than joint immobility must play a role in determining the onset and the severity of the contracture. Some of these factors are pain, inflammation, circulation and personality.

Pain is a major factor and accentuates the rapidity of the organic changes which lead to a fixed deformity. Pain also tends to increase muscular spasticity or hypertonicity which, if present, also appears to have a direct relationship to the contractural mechanism that renders shortening irreversible.

Inflammation of the joint or the surrounding structures also has a tendency to accelerate the contracture process. Whether this occurrence is due to the inflammatory

changes present, pain which accompanies any inflammatory process, or to a combination of both of these factors is yet to be resolved.

The role of muscle circulation and personality factors remains completely undetermined. Chronically disturbed circulation in a muscle maintained in a contracted position for a prolonged period may influence the permanent shortening of the contractile mechanism. Some authors have maintained that personality is an important factor in the development of these complications. References have been vague and without any attempt at evaluation.

Since this condition is considered as being preventable, the primary goal of therapy should be prophylactic. Prevention of deformity depends mainly on early recognition. Routine daily checking of all hemiplegics will quickly expose the cases with resistance to passive range of motion. Immediate steps are required in these cases to maintain full range of motion of the joints. *When spasticity is present, its reduction is* necessary. Contributory factors, such as pain and inflammation, can be managed by the use of analgesia and local application of heat modalities. When the limitation of motion is already fixed, a trial of stretching (minimal force extended over a long period of time), including traction, is indicated. If motion does not improve after 2 weeks of conservative therapy, surgical correction should be considered.

Surgical procedures which have been used include tendon lengthenings, tendon recessions, tendon releases, myotomies and capsulotomies. Included under surgical procedures is stretching, with either general or local anesthesia. Selective denervation of muscles or a rhizotomy are sometimes indicated. Once a contracture is overcome, and surgical procedure completed, a recurrence must be prevented by maintaining and performing the principles as outlined under "Prevention of Deformity."

3. **Kinanesthetic Hemiplegia.** Patients who present this abnormality have difficulty *in carrying out training procedures and the* requirements of daily living. This is in spite of the fact that they have little loss of motor power or speech disturbances. These patients are frequently considered a problem by the rehabilitation staff and the family, if their sensory difficulties are not taken into consideration.

On examination, the clinical neurologic findings are:

A. In conjunction with the usual pyramidal track findings in a hemiplegic, there is defective cutaneous and proprioceptive perception.

B. In addition to the motor deficit, there is also a major sensory disability.[8] The patient, if able to communicate, complains that (a) his arm and leg feel numb; (b) he stumbles easily (if he ambulates); (c) the soles of his feet feel padded.

He may also state that he is unable to use his hand for functional activities without using his eyes for supervision, co-ordination *and placement.*

The sensory deficits that are found on examination can be evaluated in the following manner:

A. Moderate degree of hypesthesia and hypalgesia which can be demonstrated by the method of double simultaneous stimulae test.

B. Inability to recognize a stimulus applied to a skin area, to recognize numerals written on the skin or to distinguish the presence of 2 simultaneously applied compass points (2-point tactile discrimination).

C. Inability to perceive posture or motion of the body or its part in space Perception of vibration may also be lost.

D. Inability to recognize objects by touch in the presence of normal cutaneous and proprioceptive sensations (astereognosis).

The patient with this type of sensory loss is no longer able to perceive feel and touch, in respect to space on the side of the body or to objects in space. Training must include a compensatory mechanism to substi-

tute for the disturbances in the sensory mechanism. For example, the eyes in the performance of a motor activity.

If, in the evaluation of a case of hemiplegia, one looks only for motor disability, it is rather easy to provide a therapeutic program which will be of little value to the patient and will result in failure to respond to rehabilitation procedures.

4. Sensorial changes frequently accompany hemiplegia. In this area, we are concerned with orientation to time, place and person; memory loss of recent and past events; and the inability to do simple calculations. Evaluation of these intellectual functions usually can be performed grossly by the examining physician but can be evaluated best by psychological testing which will show the remaining assets as well as the amount of cerebral deterioration.

It should be noted that sensorial defects are not present in direct relationship to the quantity of peripheral neurologic findings. Massive arteriosclerosis of the brain (shown by postmortem examination) is not correlated with massive sensorial changes. Minimal brain damage will frequently show marked disorientation and memory defects.

5. **Aphasia and Dysarthria.** In these difficult problems of management, the philosophy in evaluation and treatment should be functional, and based realistically on the needs of an individual in a communicating world—whether the problem is that of a dysarthria (inability to produce repetitive muscular movements of articulation in a smooth fashion) or aphasia ("expressive"—inability to express ideas through spoken or written language symbols; or "receptive"—difficulty in understanding oral or graphic symbols). Recently, clinical methods for establishment of prognosis and feasible treatment goals have been presented.[5]

6. **Limited Interpersonal Resources.** If, when examining a hemiplegic, one finds that, previous to the onset of the disability, his relationship to other individuals has been on a purely egocentric basis, prognosis for successful rehabilitation is usually poor. With the onset of the disability, there is an accentuation of lack of interest and concern in other people and the outside world. Rigidity and inflexibility are also mitigating factors. The formation of these defenses in the patient's life, which have probably served him well previous to the hemiplegic onset, makes a rehabilitation program difficult, as it again further isolates the patient from the outside world and makes changes unacceptable to him.

Upper-Extremity Training and Restorative Procedures

Training of the affected arm is started while the patient is developing proficiency and skill in activities of daily living with the unaffected arm. The rehabilitation of the spastic arm is difficult because of the abnormal pattern of motion which becomes apparent when the patient attempts volitional activity. When asked to flex the elbow, he elevates the shoulder and abducts and internally rotates the arm. Pronation and supination of the hand is usually attempted through a substitution mechanism of internal and external rotation of the entire extremity. Training procedures for purposeful function must be directed toward the entire extremity as the use of the hand and the fingers is dependent on the proper functioning of the shoulder, the elbow and the wrist for placing the extremity in positions of functional use

REFLEX THERAPY

Recently, interest has been shown in a training program for the upper extremity which utilizes "associated reactions" or "facilitation patterns," better known as "reflex therapy."[2]

This training program has, as its physiologic basis, the theory that a subcortical motion synergy is present which can be elicited first on a reflex basis and then, through training, to obtain a controlled volitional movement.



FIG 9. Reflex therapy class.

It has been observed in upper motor neuron involvement that associated movement reactions, reflex in nature, occur in the affected extremity when voluntary forceful motions of other parts of the body are performed. These reactions are characterized by changes in the tension of the muscles surrounding the joints of the affected extremity. This change in tension involves anatomical prime movers and antagonists simultaneously

It has long been advocated that these reflex patterns be used in the training of patients with upper motor neuron lesions. As the therapeutic program progresses, basic reflexes may be brought under willed control, and the patient is able to reproduce function motion on a voluntary basis.

Reflex patterns used in a specific manner for hemiplegic retraining can be classified in many ways. These include: (1) physiologic (normal); (2) pathologic (abnormal); (3) proprioceptive, (4) exteroceptive, (5) tonic; (6) postural; (7) righting.

Reflex patterns have been found helpful in initiating a treatment program[6] with progress as the patient increases functional volitional ability, to physiologic treatment aids. These physiologic aids are: (1) slings, for elimination of gravity; (2) skate board, a device for initiation of movement with resistance; (3) active-assistive to progressive-resistance exercises.

A type of training program following this pattern of retraining the hemiplegic arm is outlined on the next page.

Other reflexes which have been found useful include:

1. The Peters' reflex (which is used to achieve extension of the fingers). It is activated by flexing the patient's finger nails sharply 3 times, starting with the little finger and proceeding through the remaining ring, middle and index fingers. Extension of the finger spontaneously occurs.

2. Proprioceptive and exteroceptive reflexes (which include stroking, application of cold and percussion).

SELECTIVE RE-EDUCATION

Selective re-education in physical restoration of the arm and the shoulder is aimed at the extensors of the elbow, the dorsiflexors of the wrist, the supinators of the forearm and the external rotators of the shoulder. This is based on the peripheral manifesta-

REFLEX THERAPY IN HEMIPLEGICS

A. TWO-JOINT PATTERNS

Originator of Pattern	*Pattern of Motion*	*Action*
A. Magnus	1. Flexion of elbow	Head turned toward normal side. Increases elbow flexion and shoulder abduction.
B. Magnus	2. Extension of elbow	Head turned toward affected side. Increases elbow extension and shoulder abduction.
C. Magnus (Strumpel's *Pronation sign*)	3. Flexion-supination of the forearm	Head movement may facilitate action.
	4. Extension-pronation of the forearm	Increases supination by flexion of forearm. Increases pronation by extension of forearm.
D. "Chaddock's" Tendonesis	5. Wrist and finger flexion or extension	(Improved by stroking ulnar side of forearm near wrist) Wrist dorsiflexion (extension). Increases finger flexion. Wrist Plantar flexion increases finger extension.
E. Temple Fay	6. Finger extension	Put arm behind back and then hyperextend shoulder. Increases finger extension.

B. PROCEDURES OF PROGRESS OF THERAPY

1. Reflex pattern manually carried out by the therapist.
2. Slings. Therapist passively takes affected arm through motion to teach patient the pattern for head and arm, using reflex patterns.
3. Skate board. Patient has learned pattern, so the skate acts as an assistive device for weak muscles.
4 Polish board. Active motion with slight assistance.
5. Stand without any equipment. Active motion using less head motion, if possible, guiding toward normal action
6 Sit without any equipment and carry out volitional activity.
7. Apply pattern to activities of daily living.
8. Progression of improvement is usually: (a) cross shoulders and fine elbow; (b) elbow and wrist; (c) wrist and fingers; (d) fine shoulder motion.

tions of hemiplegia in which muscles can be grouped under (1) increased hypertonicity and (2) decreased hypotonicity.[11]

The muscles which have been enumerated present hypotonic involvement and are completely overpowered by their antagonists, the hypertonic groups.

Nerve block of the hyperactive muscles has proved to be an ideal method for assaying the potential of recovery of the hypoactive paretic muscle groups.[9] This procedure can be of extensive value in establishing a program of selective muscle therapy, as well as a guide to surgical denervation (de-afferentation) or tendon transplants.

If a worthwhile increment in voluntary function of the hypoactive groups follows chemical block of the nerves to the hyperactive antagonists, consideration should be given to the possible benefits of a more pro-

longed interruption of nerve conduction. The aim in the use of surgical interruption is to reduce the amount of afferent proprioceptive impulse from the hyperactive muscle and thus aid in the retraining and the strengthening of the hypotonic antagonist. Temporary interruption of conduction in the motor branches to hyperactive muscles can be carried out by application of pressure to the nerve or by transection and immediate suturing. The branches of the nerves to the muscles are identified with the aid of a stimulator at the time of operative intervention and are crushed at the furthest possible distance from the point of the entry into the muscles which they innervate. Usually, in an effort to produce a balance in the prime movers and antagonist muscle groups, nerve interruptions are also combined with tendon transfers.[18]

The most common tendon transfers are the use of the brachioradialis, the flexor carpi radialis and the flexor carpi ulnaris to act as extensors to the finger and the thumb. Section of the palmaris longus is often indicated. Previous to carrying out of operative procedures, extensive and prolonged preoperative treatment should be carried out by every available method of proprioceptive facilitation. Following any surgical procedure, physical restoration activity is further indicated to establish a balance between the functioning muscle groups so that volitional activity can be performed

AMBULATION

As soon as the hemiplegic patient is able to remain out of bed and has learned to stand at a hand rail, ambulation training follows in a logical sequence First, he is taught balance, through exercises with a support such as parallel bars or similar apparatus, through walking along the rail or between the bars, at first assisted and, finally, without assistance The next stage is ambulation outside the bars with a cane, if necessary, and under the supervision of professional personnel. As the patient increases his tolerance and gains confidence, usually over a gradual period of time, assistance from these professional personnel becomes unnecessary.

It should be pointed out that, during the walking between the bars, a principle must be adopted and an effort made to teach the patient a gait pattern as similar to the normal as is possible. Once he begins walking outside the parallel bars and shows preference for an abnormal gait pattern (and possibly shows more stability with it), he is permitted to continue in this manner. One always seeks a good cosmetic appearance, but it is more important to have the safety of the patient and ambulation than to fulfill the professional training personnel's ambition that walking be done with a "physiologic gait."

In a severely handicapped hemiplegic, difficulty may occur in the training program with marked differences present from the treatment outlined previously. Recovery of adequate balance with use of the involved side may be hopeless; therefore, it is necessary to teach him to substitute for the lost or impaired balancing powers of the involved lower extremities by using the function of the normal opposite upper extremity and the eyes.[10]

Interesting abnormalities observed in the hemiplegic, with particular emphasis to his gait pattern are: leaning toward the hemiplegic side and a tendency to lean backward. It is felt that these complications are due to disturbances in the patient's space perception, postural reflexes and proprioceptive sensory sensation.

From clinical observation, hemiplegic gaits have been classified as follows.

The Spastic Gait

Observations During the Swing Phase. The most common characteristic of the hemiplegic gait is the slowness of the motor performance of the paralyzed side.

Timing Aberration. One of the major aberrations is loss or suppression of many

of the synergistic and smoothly co-ordinated patterns of the normal gait. This can be demonstrated and observed in some hemiplegic patients with apparently minor disturbances who still possess, for example, the power to dorsiflex the foot voluntarily but cannot do so during the swing phase even if they concentrate specifically on this function. However, when they do perform this movement, we often find that, because of poor rhythm, hip flexion, dorsiflexion of the foot and flexion of the knee appear at the end rather than at the beginning of the movement, as in the normal gait pattern of the swing phase.

THE INTERMITTENT DOUBLE-STEP GAIT. In this gait pattern, the patient loses balance during the swing phase of the paralyzed limb. This loss of balance is attributed to the delay in starting of the restraining phase of the hemiplegic leg. This imbalance is controlled by the patient by a voluntary pause and momentary stopping in the restraining phase instead of the continuous cycle of restraining through propulsion and "push-off."

Abnormalities During the Stance Phase. Among those aberrations of gait in the stance phase, one of the most common is that which occurs with tightness or a contracture of the calf muscles. This is seen particularly in patients with severe hypertonus; therefore, they cannot produce the fine co-ordination of muscle action necessary in the "push-off" of the foot at the termination of the stance phase. Upon contracting, there occurs a resulting intensive plantar flexion of the foot.

EXTERNALLY ROTATED LEG. Only the patient with mild spasticity of the calf muscles and with good balance will sufficiently increase the propulsion of the good leg to overcome the spasticity of the supporting one In an effort to avoid forced propulsion of this type, the patient with marked hypertonus prefers to rotate his whole leg externally so that the hemiplegic foot is directed sidewise. This externally rotated leg gives him a gait that releases him from the need to overcome the tension of the spastic foot and calf muscles and gives better balance in the frontal plane and the direction of progression.

THE HOPPING GAIT. This is an extremely useful gait. The patient tends to lose his balance forward abnormally during the stance phase of the hemiplegic leg. The hemiplegic loses his balance the moment weight is placed on the involved leg. In order to regain his balance, he will execute a short swing of the good leg and then pause. In this manner, the good leg is never placed in front of the hemiplegic one, therefore maintaining the patient in an upright position.

BENDING FORWARD. Another method of ambulation which may occur alone or in combination with other postural positions is seen in those patients who bend forward at the waist at the beginning of the supporting phase of the paralytic leg. In this manner the patient is able to lose the balance forward without having to overcome the hypertonicity in the hemiplegic leg while still maintaining performance of the swing phase of the good leg.

SIDEWARD BENDING. Often, the patient is unable to achieve sufficient flexion at the hip to initiate the swing phase of the hemiplegic leg. A compensatory mechanism is to thrust the trunk to the good side and backward, thus producing a tilt of the pelvis upward on the involved side. This permits performance of the swing phase of the extended hemiplegic leg by means of a backward thrust of the trunk. The entire walk may be executed by using trunk movements, that is, by leaning forward to prepare for the swing of the good leg, then toward the good side and backward to initiate the swing phase of the hemiplegic limb.

THE FLACCID GAIT

There are those hemiplegics who show prolonged flaccidity. This is usually evi-

denced in both involved extremities. These patients often develop, with time and training, enough stability in their lower extremities to enable them to ambulate and bear weight without bracing of the involved knee.

Circumduction. Such patients with a predominately flaccid hemiplegia will circumduct the leg during the swing phase by thrusting the trunk toward the good side of the body and backward, so that the pelvis on the involved side is raised, and the leg swings through. If there is sufficient strength in the muscles of the lumbar region, aid in lifting the involved pelvis may occur. This circumduction, in contrast with that described under the "Spastic Gait," is pendulous in appearance. During the early training period, the leg comes to rest in front of or across the supporting leg at the completion of the swing phase, and supervision is necessary to overcome this tendency.

Reversibility of the Hemiplegic Gait

There appears to be clinical and experimental evidence for potential reversibility of the hemiplegic gait.[17] Analysis of many hemiplegics reveals that motor recovery occurs spontaneously in a selective fashion.

Postural Muscles. Motor recovery occurs first in the extensor muscles of the knee and the ankle. In association with this, there is a relative hypotonus in the antagonistic flexors of the knee and the dorsiflexors of the foot. On examination, it is reflected in the contrast between the patient's ability to extend the knee strongly through a wide arc of movement and the inability to flex the knee when in the prone position. A similar imbalance is seen between the strongly contracting plantar flexors and the weak dorsiflexors of the foot

Lateral Leg Asynergia. The phenomenon of the delayed return of function in the laterally placed muscles of the lower extremities can be observed. This results in gross impairment of synergistic contraction of the internal rotators of the hip, of the biceps femorus and of the muscles producing the movement of dorsiflexion of the ankle in eversion.

Delayed Return in Proximal Muscles. Persistent weakness in proximal muscle groups is also observed. This is also present in patients who have had spontaneous recovery to a considerable degree. Gross evidence of weakness in the proximal muscles is seen in the persistence of a Trendelenberg limb until late in the recovery phase, and in the poor performance on clinical testing of the movement of abduction at the hip joint. Satisfactory volitional control of hip flexion is observed only following correction of the imbalances between the rotator muscles of the hip, and the abductor and the adductor groups.

Knee Involvement. A frequent finding in this condition is the inability of the patient to extend the leg completely at the knee, especially in the test pattern with the hip placed in flexion. From a muscle involvement viewpoint, there is paresis of the vastis medialis and the rectus femoris.

Altering the Hemiplegic Gait

Rigid Control of Ambulation. Ambulation is carried out with the knee suitably splinted, and bracing is continued until the extensor muscles of the knee or the ankle are able to support the body weight; however, it is recommended that, when flexor function is occurring in the recovery cycle, ambulation should be severely curtailed.[16] During this period of curtailed ambulation, there should be no slackening in the non-weight-bearing resistive exercises which are directed specifically toward retraining of the flexor groups. Full ambulation is permitted again when, from a clinical standpoint, the flexor muscles have recovered sufficient strength to permit their competing successfully with the opposing extensor muscles This can be ascertained when the patient, in a standing position, can flex the knee without any concomitant flexion of the hip

Selective Re-education. Emphasis is placed on the retraining of the flexor

synergy. This is carried out by painful stimuli (electric, pin, pressure) in combination with manual resistance to reinforce the response of synergistic withdrawal through contraction of the flexor muscles. Later, re-education exercises are prescribed for the individual flexor muscles of knee, foot and hip joints. Particular emphasis is placed on the increasing of strength in the biceps femoris and the long extensors of the toes. During these exercise procedures, the positioning of the thigh in internal rotation aids in increasing the amplitude of contraction in the selected muscles.

Retraining of motion in the hip is also undertaken in a selective phase. Hip abduction is reinforced by simultaneous spine extension and traction on the leg. There is a tendency to perform hip flexion with the femur held in external rotation. In an effort to prevent this, hip flexion retraining is carried out with the femur held in a position of moderate rotation. Retraining of the movements of hip extension are attempted several weeks after the movements of hip flexion and abduction.

The patient's inability to perform terminal extension of the knee persists until the last stage of recovery, regardless of the attempts or exercise programs carried out; however, during re-education of this movement, it is recommended that the program be performed in a non-weight-bearing position with the elimination of gravity. Increase in the strength of the vastus medialis muscle can be found as knee extension improves.

Chemical Nerve Blocks. To permit more accurate examination of residual strength and function in relatively hypotonic muscle groups, development of a technic of chemical block conduction in the nerve trunks supplying the stronger antagonistic extensor muscles has been developed[9] This procedure can be of inestimable value in determining the rehabilitation potential of individual patients from a standpoint of selective muscle therapy, as well as a guide to surgical intervention of nerve or tendon transplantations. Following a complete nerve block, an examination of the function of a hypotonic muscle group is carried out, and, if increased volitional contractions are observed, muscle retraining is continued. However, if increased volitional ability is not found, it is felt that prolonged and expensive retraining is not justified. One can also ascertain, through a conduction block, whether an extensor overactivity at either the knee or the ankle is primarily incriminated in the production of the hemiplegic gait.

Surgical Interruption of Nerve Conduction. When a satisfactory increment in the strength of the flexor muscles is observed following anesthetic block of the nerve to their antagonists, the possibility of surgical neurotripsy can be considered. Following the surgical procedure, intensive treatment to the flexor groups (dorsi flexors of the foot and flexors of the knee) can be made more intensive with more enduring results. Also, after reduction or elimination of the strong plantar thrust and clonus at the ankle, braces can be either dispensed with or reduced in weight. The neurotripsy or interruption of conduction is performed by the application of pressure to the nerve, or transection and immediate suturing of the nerve. These procedures are preferred to a neurectomy because of the availability of reversibility of the conduction defect by the former means. Branches to the muscles are identified by the aid of a stimulator and then are crushed at the furthest possible distance from their point of entrance into the muscle. The main emphasis is to reduce the proprioceptive impulses which occur from hyperactive muscle groups, and no effort is made at mechanical blocking of the large diameter "motor" fibers.

Surgery of Tendons and Muscles. In the lower extremities, as a follow-up and in conjunction with the processes which have been described, surgery has been of value with particular reference to tendon and mus-

cle procedures. Great benefit has been obtained from the Strayer operation of gastrocnemius recession. This has been found to be helpful where there has been great reflex hyperirritability of this muscle group in association with tendencies toward contractor or persistent clonus. The varus deformity of the foot, which presents such a mitigating factor in a good gait pattern, can be corrected by performing a tibialis posticus tendinotomy in conjunction with the Strayer procedure.[15] Consideration must also be given to fascia contractures and shortening, which must be controlled.

BRACING

In the early stages, as has been outlined under the activity phase of the rehabilitation program, braces should be light, cheap, transferrable and are usually of a temporary nature. During the early stage they are used for protection of proximal groups and for contractual and proprioceptive stimulation.

As the patient progresses through his retraining phase, there may be interference caused by certain persistent functional impairments of the lower extremities. These impairments, due to residual motor difficulties, include foot-drop, with or without associated disabilities of the forefoot, instability of the knee and disturbances in rotation, adduction and abduction of the thigh. In some cases, it is necessary to consider the use of supportive appliances to obtain effective ambulation.

The stability of the joints of the hemiplegic extremities determines the type of brace to be used and the extent to which mobility can be permitted in the artificial joints. It is necessary to understand that the patient presents a different clinical function from the prone or the supine as compared with the weight-bearing position; therefore, the prescription of a supportive device must be based on the evaluation of the patient and his disability in the weight-bearing, proprioceptive, contactual stress stimulation position.

Basically, the function of a brace for a hemiplegic patient is not to support the body weight but to maintain the body postural alignment as normally as is possible through its splinting action. The effect should be to help, by its external supports, the weakened muscles responsible for maintaining a stabilized position. The brace must restore stability, if necessary, and attempt to preserve the maximal permissible joint motion. It should re-establish weight-bearing ability and facilitate locomotion. A brace can never substitute for loss of muscle tone or lack of co-ordination. It should aid in preventing deformities but never can correct them.

A brace should be fitted and aligned properly with the artificial ankle joint placed just above the tip of the medial malleolus in line with the transverse of the talotibial joint. If a knee joint is used, it should be located opposite the mid-point of the medial and the lateral condyles of the femur. The hip joint, if necessary, should be located at the level of the tip of the greater trochanter and slightly anterior to it.

Bracing for the Foot or the Ankle

In the hemiplegic bracing for the foot or the ankle should (1) allow for the body weight to be distributed evenly over the plantar surface of the foot; (2) give good lateral stability of the foot despite the presence of imbalance; (3) retain the maximal permissible amount of "push-off" during locomotion; (4) permit the optimal range of motion in the ankle joint.

The disabilities found in the foot or the ankle are either simple or complicated drop foot. A simple drop foot shows no deviation of the forefoot or heel. The complicated drop foot occurs when the forefoot or the heel shows medial or lateral deviation.

Mild Drop Foot. When weakness of the dorsiflexors is very mild with little, if any, increased muscle tone in the plantar flexor muscle group, and with co-ordinated function present, a simple spring support may

be used. This "shoe horn" support consists of a flat spring attached to the heel of the shoe and a cuff counterpoint midway up the calf.

A simple wire brace attached to the heel, run up the posterior aspect of the leg, having a counterpoint in a cuff present at the calf, also furnishes some stability to the leg. It can be used only where there is mild weakness of the dorsiflexors with a stable ankle and little, if any, increased tone in the plantar flexor muscles.

Other simple types of apparatus which have been found to be helpful include a single-bar brace on the medial or lateral aspect of the leg or the use of a simple elastic support. The use of such devices has been recommended when the weak dorsiflexor muscles become easily fatigued or are unable to contract effectively when used against the force of gravity or footwear. These devices are useful when there is a clinical impression that the involved muscles will increase their functional recovery.

Moderate and Severe Simple Drop Foot. If the condition appears to be of a permanent nature, and the brace is to be worn indefinitely, then to give stability to the ankle and the foot, a double-bar brace is indicated. Experience has shown that a stirrup-type ankle joint should be used. If there is only a mild amount of muscle imbalance, with no evidence of spasticity in the plantar flexor muscles, then the Klenzak-Pope spring stirrup gives efficient results. The automatic adjustment of the toe-lift spring permits excellent locomotion with a tendency to prevent stumbling or tripping because of more normal function at the ankle with toe elevation. The degree of elevation of the toes is easily adjusted by varying the tension of the spring in the artificial ankle stirrup joint. If spasticity is present in the plantar flexors, this spring stirrup should not be used, as it has been demonstrated that further spasticity of the plantar muscle groups occurs. If these conditions are present, then a regular stirrup with a 90° posterior stop is employed.

Stirrups have been fabricated and are now available for easy transference of a brace from one shoe to another—a desirable and necessary cosmetic adjustment.

Complicated Drop Foot with Varus Deviation. This is a common disability in the hemiplegic foot. It results from the pull of stronger tibialis anterior or tibialis posterior muscles opposite to the weak or totally paralyzed peroneal muscles. The brace should be of the drop-bar-stirrup type with ankle stops for limited motion with a T or Y strap affixed to the lateral border of the shoe, pulling to the medial upright bar at the ankle joint. This will lift the lateral border of the foot and allow the body weight to be distributed over the entire plantar surface of the foot. It is important to remember that the T strap should be placed at the site of the lateral motion of the foot. This motion usually takes place at the talocalcaneal and the midtarsal joints; therefore, the T or Y strap should be placed well forward in front of the upright bars and over the axis of these joints.

Complicated Drop Foot with Valgus Deviation. The double-upright-bar stirrup-type base with posterior stop is used with a T or Y strap placed on the metal sole of the shoe over the apex of talocalcaneal and the midtarsal joints, fastening over the lateral bar of the brace.

Bracing for the Knee

In a certain percentage of hemiplegic patients, a varying degree of residual weakness of the muscles around the knee joint may persist. Hyperextension or incomplete extension may occur. The type of brace to be used for stability purposes depends largely on the remaining function of the muscles involved. If the involvement is of a mild type, a long leg brace with a free knee joint of 180° is all that is required. This brace will stabilize a knee sufficiently during the weight-bearing phase and will prevent hyperextension. If more stability is needed at the knee, a single drop-lock knee brace can be

used. The lock should be placed on the medial knee bar so that the hemiplegic patient can open or close it easily and effectively with his unaffected arm. If marked instability is present, a long leg brace with double drop-locks at the knees is essential, as it must give firm lateral support and prevent rotation. Mention should be given to the site of the thigh cuff to which the lateral bars are fixed. This cuff should extend to just below the gluteal crease, and in some instances consideration is given to a gluteal seat, an ischial support, or a reversed butterfly ring.

Training in the Use of the Supportive Apparatus

Training in the use of the supportive apparatus should be provided for the patient who wears it. A brace which gives lateral stability to the knee or the ankle imposes certain limitations in the normal anatomic rotary component of the leg during locomotion. This causes alterations in the integration of the individual's body segments and dynamic balances. There is also a change in the patient's gait due to inertia and brace weight. Speed and acceleration modifications are caused by the added weight and mechanical limitations of the brace. To correct these factors, training is necessary for good balance and muscular coordination, effective ambulation and acceptable cosmetic gait appearance.

CONCLUSION

Hemiplegia presents one of the most challenging problems in medicine today, both in total numbers and therapeutic complexities With a dynamic approach to the problems of hemiplegics using rehabilitation technics developed to meet the total needs of the individual, much can be offered, and most hemiplegics can be trained to lives of self-sufficiency and acceptance.

Consideration must be given to shifting the emphasis and concentration from the disability to the diagnosis of the patient's abilities. Incapacities have a tendency to dominate the picture psychologically and sociologically, so that the individual is forgotten, and the paralyzed extremities become paramount in the medical approach The disability, for every patient, has special meaning which has to be resolved before his capability can be released. Medical concentration upon the disability tends to conform and fix the patient's psychological maladjustment. A rehabilitation program must include a mobilization and psychic investment of the remaining assets of the patient, such as his functioning muscular and intellectual capacities and interpersonal resources.

THE CHALLENGE OF THE QUADRIPLEGIC AND HIS REHABILITATION

The increasing rate of survival of patients with cervical cord lesions poses a challenging problem in connection with various facets of their disability and rehabilitation. Bors[3] reviewed this medical problem quite extensively by analyzing 233 cases at the Paraplegic Center of the Veterans' Administration Hospital in Long Beach, Calif. Previously, Munro[14] had reported his experiences with 101 traumatic quadriplegic patients.

A review of hospital and rehabilitation center records reveals the average inpatient stay for those persons who reach suitable goals in rehabilitation is 2 years; as compared with 3+ years for those who remain in a hospital under need of definitive medical care, with subsequent transference to a custodial or nursing home unit; and 1 year and 3 months for those who die.

The challenging problems which these patients present vary as to whether there is a complete cervical cord lesion (physiologic or anatomic transection), or an incomplete (partial) lesion with varying degrees of sensory and motor deficits.

ETIOLOGY

Trauma has been found to be the causative factor in over 90 per cent of cases. The 3 most common traumatic involvements are (1) automobile accidents; (2) diving mishaps; and (3) falls (usually on steps), with the frequency of occurrence in that order. Diseases such as poliomyelitis, multiple sclerosis and degenerative process account for the other 10 per cent.

EARLY TREATMENT

The need for and the type of early treatment of spinal cord injuries was evaluated recently by Comarr and Kaufman.[3] It was concluded that a laminectomy is indicated in the presence of (1) spinal cord block; (2) doubt as to whether the cord lesion is complete or incomplete; and (3) progressive neurologic deficit on clinical evaluation.

A complete transection of the cord is a contraindication to laminectomy; however, this is a difficult diagnosis to make without surgical intervention.

It is axiomatic that one does not treat the patient through the x-ray findings, but by the clinical evidence on physical examination. Severe fracture-dislocations of the cervical vertebrae may not cause a transection of the cord but may occasionally be compatible with the survival of the spinal cord. Spinal fluid block and/or vertebral deformity are first treated by skeletal traction; and if this attempt at conservative therapy fails, then a laminectomy is performed, unless the other indications as listed above are present

In the differential diagnosis and evaluation at the time of the initial physical examination by the physician, one should remember that, in diving accidents especially those occurring in the surf, hyperextension injuries[16] occur frequently. These patients have edema and central cord damage from the impact of the ligamentum flavum and/or the nucleus pulposis. Without this knowledge, one may conclude that these patients have sustained a rapid cervical dislocation and subsequent spontaneous reduction.

Following a spinal cord injury, the most favorable interval of time for performance of a laminectomy is found to range from 24 hours up to and including 1 month after onset.[4] A delay in performing a laminectomy does not necessarily impede the rate of return of motor and sensory function but, in many cases, may be helpful. The time element in performing the operative procedure becomes important from the standpoint of edema of the cord and resulting spinal fluid block.[14]

In return of sensory and motor function, peripheral tactile sensitivity occurs first, followed by pain and temperature sense, with peripheral motor function last; and this is followed by motor and sensory control of the bladder. This sequence and pattern in spinal-cord-function recovery applies to patients who have had laminectomies, as well as to those who have been treated without operative intervention.

In conjunction with skeletal traction and a laminectomy (if necessary), early medical care must also take into consideration definitive measures of treatment. These include maintenance of a patent airway for respiratory purposes, nutritional balance and control of the disturbed urinary and fecal elimination processes. Pain and emotional lability must also be depressed. In disturbances of the homeostatic mechanisms secondary to "spinal shock," provisions must be made for elimination of body heat and stabilization of the volume of the circulating blood. Good bed-positioning, with proper body alignment is also necessary. The use of a Stryker Frame is helpful in allowing nursing and medical personnel to carry out the definitive medical procedures necessary. Figure 10 demonstrates this apparatus, modified for mobility and propulsion by medical personnel or by the patient himself, as he improves from his early acute state.

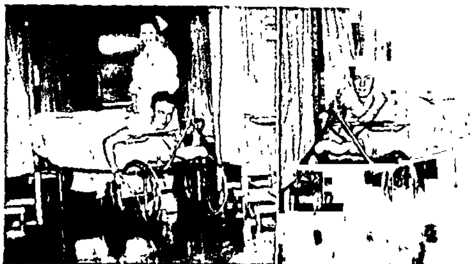


FIG 10. Modified Stryker frame with big wheels with rims on front for mobilization purposes.

COMPLICATIONS

Hyperreflexia and Spasticity

Too often, the medical problems and handling of the quadriplegic patient have been compared with those of the paraplegic. The quadriplegic, after the termination of the period of spinal shock, has a double problem of complication: (1) skeletal spasticity and (2) automatic hyperreflexia.

All patients with a cervical spinal cord injury, as well as those with injury to the spinal cord above the sixth thoracic vertebrae, have this unique involvement of both autonomic hyperreflexia and skeletal spasticity.

Skeletal Spasticity. The clinical findings in this condition are increased muscle tone, increased deep tendon reflexes, pathologic pyramidal track signs, and usually characteristic postural patterns or positions of the extremities in flexion and adduction. Conservative methods to correct or control the skeletal spasticity include splinting of the extremities, bracing, hydrotherapy, passive exercise, weight-bearing and electrotherapy. In many cases these approaches are sufficient to alleviate this condition; however, if these treatment modalities are insufficient, operative procedures are helpful. They are performed centrally on the spinal cord or nerve root, or peripherally on the plexus or peripheral nerve Procedures performed centrally include the injection of absolute alcohol subthecally, the performance of rhizotomies, and/or a chordotomy

Peripheral procedures which can be performed and have been found useful in lower extremity skeletal spasticity to overcome abnormal postural patterns are those of obturator neurectomy and/or a psoas muscle myotomy and/or adductor muscle tenotomy. Hamstring and Achilles tendon releases and lengthening have also been found helpful.

If skeletal spasticity of the upper extremities is severe, this usually subsides when the proprioceptive impulses from the lower extremities are controlled or eliminated by a central or peripheral neurosurgical procedure. Therefore, definitive procedures for upper extremity spasticity are not indicated or necessary.

The presence of a focus of irritation or a foreign body may accentuate the skeletal spasticity which is present. Conditions such as a paronychia of the toe, decubitus ulcers, bladder calculi and malfitting stockings and shoes are common causes. Careful clinical investigation must be performed to eliminate all sources of this type to control the skeletal spasticity so that successful rehabilitation can be accomplished.

Autonomic Hyperreflexia. The mechanisms of pathologic autonomic hyperreflexia have been studied extensively. This syndrome consists of paroxysmal hypertension, headache, bradycardia, diaphoresis, posterial hypotension and visceral spasm. These symptoms must be recognized and treated symptomatically, since fatalities have been

reported as occurring from the paroxysmal hypertension, and strict and rigid attention must be given to this abnormality.

Recently, Kurnick stated that excellent results and control have been obtained by the use of a long-lasting ganglionic blocking agent, hexamethonium hydrochloride,[10] with the oral intake of this medication ranging from 125 to 750 mg. every 3 to 6 hours during the acute phase. Tetraethyl ammonium chloride has also been found useful in this condition.

Decubitus Ulcer

The incidence of decubitus ulcer is found to be twice as great in the quadriplegic as in the paraplegic patient. This may not seem a surprising statistic if one attempts to evaluate this finding mainly on the basis that the quadriplegic patient has denervation and lack of sensory perception in more skin area. Besides the greater surface of the body which is involved, another factor is important—the disturbed vasomotor function.[13] The latter supports the contention that vasomotor disturbances contribute to the etiology of decubitus ulcer. In the quadriplegic, this is demonstrated by the appearance of ulcers in regions without disturbed sensation, but with disturbed autonomic vasomotor functions, such as the forehead, the nose, the chin or the occiputs—areas which are above the level of the cervical cord lesion.

Bladder Function

It is possible, through comprehensive rehabilitation and bladder training (or retraining) programs, to establish bladder control without a catheter in approximately 20 per cent of the patients. The remaining 80 per cent find it necessary to use catheter drainage (urethral or suprapubic).[7]

Bladder rehabilitation depends numerically, to a degree, upon the level and the extent of the cervical cord lesion. Patients with complete lesions (physiologic or anatomic transections) function equally well or even better than those with incomplete lesions. Standard operative interventions such as alcohol blocks, pudendal neurotomy, transurethral resection are helpful but not as important in improving bladder function for the quadriplegic as compared with the paraplegic. This is because of the quadriplegic's greater neurologic deficit which does not permit him to use abdominal or manual pressure for evacuation of the viscus. Therefore, in many cases, the quadriplegic must remain on catheter drainage after such operations or use a rubber urinal, while the paraplegic can dispense with this type of apparatus.



Fig. 11. Quadriplegic on tilt-board for assuming upright weight-bearing position.

Other urologic complications which occur include fistulas, hydronephrosis, strictures and renal calculi.

Recently, it has been demonstrated that the use of acetylsalicylic acid or salicyamide (10 gr., once daily) can be quite helpful in the prevention of recurrence of bladder or renal calculosis. Other factors which are useful in management of the patient in prevention of urinary complications include con-



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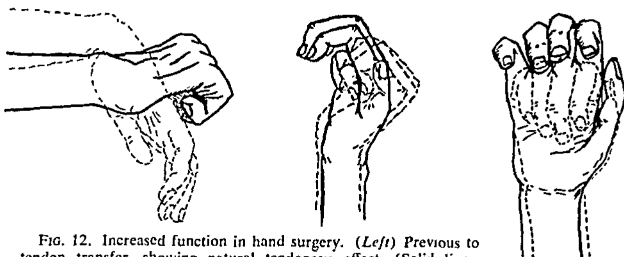


FIG. 12. Increased function in hand surgery. (*Left*) Previous to tendon transfer, showing natural tendonesis effect. (Solid lines, before extension of the wrist. Broken lines, after extension of the wrist.) (*Center*) Side view postoperatively. Brachioradialis and extensor carpi radialis longus muscles were transferred to act as common finger extensors. (Broken lines show function of hand before operative procedure; solid lines, after operative procedure.) (*Right*) Front view postoperatively. Brachioradialis and extensor carpi radialis longus muscles were transferred to act as common finger extensors. (Broken lines show function of hand before operative procedure; solid lines, after operative procedure.)

trol of the protein metabolism, hydration and early mobilization in an upright weight-bearing position by the use of a tilt board (Fig. 11).

PULMONARY COMPLICATIONS

Pulmonary atelectosis is a frequent complication. Simple upper respiratory infection may precipitate this condition if there is a defective mechanism of breathing. This may be due to paralysis of the lateral part of the diaphragm and some or all of the intercostal and abdominal musculature. Abdominal support by the use of a binder, placing of the bed in the Trendelenberg position, liquefaction of the viscous mucus within the airways by means of a detergent applied with a nebulizer, and positive pressure breathing are useful Tracheotomies, at times, have been indicated. The patient's vital capacity is decreased, and this measurement should be recorded Treatment consists, also, of definitive pulmonary breathing exercises.

FRACTURES

There is a lower incidence of fracture among quadriplegic than paraplegic patients. The usual cause is trauma, secondary to accidental injury; however, they also occur in association with osteoporesis and manipulation of an extremity. The most common bones which are involved include the shaft of the femur or the tibia, or the femoral neck. It has been demonstrated that open surgical procedures such as the use of intramedullary pins or skeletal traction should be avoided because of the complications of osteomyelitis and circulatory disorders. Healing will occur readily,[6] and subsequent bone deformities and pseudarthrosis do not present extensive mitigating factors in the rehabilitation program.

REHABILITATION

SELF-CARE AND EXERCISE ACTIVITIES

It is apparent that the degree of physical restoration of the quadriplegic is more difficult than that of the paraplegic. The physical limitation of the patient is determined by the *level and the extent* of the spinal cord injury. On clinical examination of patients with a cervical cord disturbance, the majority are found to have a sensory and motor

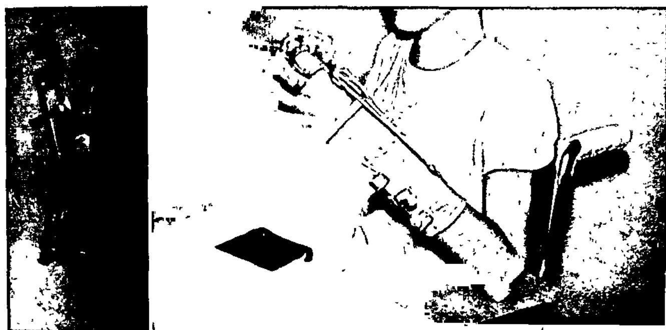


FIG. 13. Bisgrove device. (*Left*) Voluntary wrist extension, finger flexion hand splint. (*Right*) Device being used by patient.

deficit at the sixth and the seventh cervical vertebrae. Motor control is present for shoulder abduction, forward flexion and extension, elbow flexion, and wrist extension in association with the natural tenodesis effect of finger flexion on wrist extension. Motor deficits and lack of voluntary control include that of function of the fingers of the hand, and wrist flexion and elbow extension.

Reconstruction of Function of the Hand by Surgery

Surgery for the reconstruction of the quadriplegic hand presents a difficult problem.

Surgical procedures have included tendon transplantation, artificial tenodesis (with or without arthrodesis of the wrist joint).[1] In the past, no benefit or limited benefit appeared to be derived by the patient in performing functional activities. Recently, a newer combination of tendon transplantations has been presented.[12] This includes the use of functioning muscles, the brachioradialis and the extensor carpi radialis longus transferred to act as finger extensors in association with a bone block (Montgomery procedure) between the first and the second metacarpal bones. The bone block is performed for the purpose of providing opposition between the thumb and the second and the third fingers. Increased success and function has occurred in this latest operative approach (Fig. 12).

In an effort to improve the evaluation and testing of muscles and their tendons before transplants or operative procedures are carried out, electromyographic grading and determinations of function of muscles are performed.[9]

One of the reasons for the low success rate for surgical procedures and hand restoration of the quadriplegic is the loss of exteroceptive and proprioceptive perception (sensory deficit) which is present in addition to the motor paralysis.

ORTHOPAEDIC APPLIANCES

At the present time there are four exoskeletal devices available to aid a person with limitation of function in the upper extremities These are (1) the Bisgrove Device; (2) the Lionel Hand; (3) the pneumatic arm; and (4) the split-hook (Nyquist).

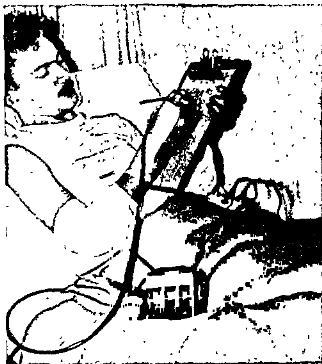


FIG. 14. Lionel hand used by patient in functional hand activities.

THE BISGROVE HAND[2]

This operates by a gear mechanism, with the activating force being supplied by the functioning wrist extensors, permitting finger flexion with tip prehension between the thumb and the index finger, and 3-jaw opposition of the thumb against the tips of the index and the middle fingers. This appliance has been found to be quite useful where only light objects need to be manipulated, such as in clerical procedures, art work, eating or similar activities in which the hand needs only steadiness and tactile perception (Fig. 13).

THE LIONEL HAND

The Lionel hand (Fig. 14) functions in a manner similar to the Bisgrove hand, but operates by an electric motor and rheostat mechanism, the activating force being electricity supplied from an external source. This is used where the wrist extensors are not present or are quite weak. Prehension of the thumb and the index finger, and strength of opposition is controlled by a mechanical gear arrangement in the appliance.

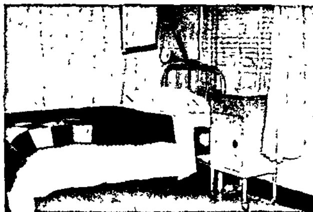


FIG. 15. Trapeze bar used for bed-transfer activities.

THE PNEUMATIC ARM

The pneumatic arm principle,[8] in which carbon dioxide under pressure in a cylinder is used as a motive force for movement of a mechanical part, has recently been adjusted for use as an artificial muscle.[11] Prehension and finger opposition are achieved through the activation of the gear mechanism of a hand splint such as the Bisgrove or the Warm Springs type.

THE SPLIT-HOOK

The split-hook has 4 variations,[15] depending on the terminal device—Dorrance Adult, Dorrance Child, Northrup and APRL (Army Prosthetic Research Laboratory). The neurologic deficit which indicates the wearing of this type of prosthesis resembles that which requires the application of the Bisgrove hand. The split-hook is used for the purpose of handling of heavier objects which may be required in daily pursuits such as the performance of bench work, soldering or assembly procedures. The shoulder girdle musculature must be of sufficient strength to operate the cable hook and terminal device and place the prosthesis in functional working positions.

It should be pointed out that, from a psychological evaluation viewpoint, appliances do not meet with easy acceptance by the patient. It is interesting to note how tenaciously these patients cling to substitutions,



FIG. 16. Sliding board used by quadriplegic for transfer from bed to wheel chair and from wheel chair to bed.

trick movements and any procedure which will give them some type of function, however cumbersome or uncosmetic it may seem, rather than to submit to the wearing of what would appear to be a necessary assistive device.

Contrary to the attitude toward assistive hand units, other devices for self-care are readily accepted, be they cockup splints, special built-up spoons, forks or pencil holders or other units for personal use, such as eating or smoking.

SELF-CARE

Through special training in "activities of daily living," some quadriplegics can be taught to care for their own feeding, dressing, toilette and hygienic needs independently.

With the use of a trapeze bar on the bed, (Fig. 15) a sliding board and a suitable wheel chair having removable arms and footboards patients can learn to get themselves from the bed to the wheel chair and from the wheel chair to the bed without assistance, even with a minimum of upper extremity motor power. Proper equipment is necessary, and the patient must be conditioned from a general body viewpoint, so that he can carry out these exertional and functional activities (Figs. 16 & 17).



FIG. 17. Patients participating in general body-conditioning program.

In the feeding area of "activities of daily living," it is found that only a small percentage of patients remain entirely dependent on outside help for feeding after definitive rehabilitation training. Most of the patients, though, do need some help from others in preparing their food (or through assistive devices) in order to assure themselves the proper food and nutritional intake.

In the progression of the mobilization program from complete bed care, to a wheel chair, to physical activities within the limits of the parameters of the patient's disability, he first uses a tilt board (Fig. 11) to assume the standing position. As tolerance is developed, transference to independent standing in parallel bars or with a standing table or frame is achieved. In an effort to stabilize the patient for acceptable posture and secure position, long leg braces with bilateral ring drop locks at the knees are used. Generally, a pelvis band is not necessary, but a well-fitted corset, extending from above the inferior spine of the scapular area posterially



Fig. 18. Quadriplegic ambulating with long leg braces and underarm crutches.

and the inguinal area anteriorally, is used. The use of the corset helps to maintain good sitting balance when in a wheel chair, aids in splinting the thorax and the abdominal area and is an aid in respiratory function. In contradistinction to a body brace, it allows the patient more flexibility, so that the activities of daily living can be performed.

Few quadriplegic patients are able to ambulate, although this is possible, in selective cases, if a person has the combination of proper stature, athletic ability and cervical involvement. In most instances, though, the goal of physical restoration is that of wheel chair activities with bracing and ambulation used only within parallel bars or work table

Fig. 19. (*Left*) Assumption of standing position for work pursuits. (*Right*) Adapted equipment for upper-extremity strengthening.

situations. Most patients are able to propel a wheel chair with or without special hand controls (friction strap, knobs) (Fig. 18).

In regard to exercise activities, it has been recommended that, if at all possible, these patients should assume the standing position with their braces, standing frame or tilt board, at least 1 hour a day. These procedures are necessary for the prevention of complications such as osteoporesis, urinary calculi, and for the maintenance of nitrogen balance and homeostatic mechanisms. Exercise procedures to maintain the strength and the power of the upper extremities must be performed continually (Fig. 19).

With special training and suitable hand controls, many quadriplegic patients can drive an automobile. The equipment which is needed consists of a spinner for the steering wheel, and combined hand gas and brake controls in conjunction with an automatic transmission (Fig. 20).

OCCUPATIONAL ADJUSTMENT

The employment figure for quadriplegic patients is still very low. Statistics for gainful employment of paraplegics are from 60 to 70 per cent; however, in quadriplegics this percentage drops sharply, averaging approximately 16 per cent.[5]

Analyzing the activities of the quadriplegic patients who do gainful occupations, their work pursuits are found to be in the fields of general office work, accounting, bookkeeping, sales, insurance, art, light assembly procedures and broadcasting.

In the analysis of the occupations followed by quadriplegics, two main factors are found. These are the utilization of the voice, and the skillful manipulation of the upper extremities in light-energy work requirements.

Future employment opportunities for the quadriplegic must be fully and adequately explored and exploited for the successful occupational placement of the quadriplegic in gainful pursuits, taking these two factors into consideration.



Fig. 20. Patient receiving training for transfer from wheel chair to automobile and from automobile to wheel chair.

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Satisfacer le Necessitates del Patiente Hemiplegic

Summario in Interlingua

Iste articulo es concernite con un evalutation del methodos therapeutic disponibile pro restablir le patiente qui ha suffrite un accidente cerebro-vascular con resultante hemiplegia. Restablir le patiente, in iste senso, significa render le capace a funger adequatemente in le ambiente de su domicilio e in su rolo social e industrial in despecto del damnos organic que ha occurrite. Le articulo sublinea le importantia del po-

tential que le patiente ha in reserva sed que ille pote utilisar solmente con le adjuta del methodologia scientific e technic providite per le medico e le personal de rehabilitation.

Le varie phases e aspectos del rehabilitation es discutite in detalio, incluse prevention de deformitates, correction de deterioration muscular per activitate e processos mobilisatori, e—finalmente—le tractamento de defectos residue per medio de technicas orthopedic e neurochirurgic.

Es delineate le tres divisiones principal del thema de invaliditate physic, i.e. (1) perdita de habilitates communicatori (per exemplo, perdita del parola), (2) le extremitates superior e lor rolo in activitates professional, e (3) ambulation con securitate e apparentia cosmetic.

Le Problema del Quadriplegico e su Rehabilitation

Summario in Interlingua

Es presentate un revista comprehensive del tractamento de patientes qui suffre de dysfunction del medulla spinal in le area cerebral, secundari a trauma o a morbo.

Attention es prestate a mesuras preventive in le forma de un prompte intervention energic, con consideration del disturbationes que occurre in le mechanismo homeostatic, de dysfunction vesical e intestinal, de deficit sensori, e de perdita de function motori, como etiam del trauma psychologic que inhere in iste typo de problema medical.

Es delineate le methodos currentemente disponibile pro le restauration physic del patiente, incluse methodos de restauration del extremitates superior per medios chirurgic e per medio de dispositivos exteroskeletic.

Es discutite le possibilitate de ambulation in casos seligite.

Es sublineate le possibilitate selective de activitate professional. Le objectivo ab iste puncto de vista es le utilisation del inherente capabilitates del patiente e—in multe casos—del ressources latente que ha remanite intacte, como per exemplo le capacitate de communicar per le voce scholate.

11

Perception of Verticality in Hemiplegic Patients in Relation to Rehabilitation*

JAN H. BRUELL, PH.D., AND MIECZYSLAW PESZCZYNSKI, M.D.

THE PROBLEM

Since World War I many clinical studies have been published which reported disturbances of space perception in brain-injured patients.[6,7] The visual perception of verticality, in particular, has appeared to be disturbed in many patients. The present study was designed to provide more information about the diagnostic usefulness of this disturbance. In addition, this study attempted to assess the prognostic value of the disturbance for rehabilitation training of hemiplegic patients.

Unfortunately, many of the early studies did not present quantitative data. Observations were made on only a few patients, and comparisons with the performance of normal control subjects were lacking.

More recently, the phenomenon has been studied in the laboratory under more controlled conditions. In these objective studies testing is performed in a darkroom, thus eliminating secondary visual cues of verticality. The only object visible to the patient is a tilted luminous rod. The patient has the task of moving the rod until it appears vertical to him, and deviations of these adjustments from the gravitational vertical are measured. The first extensive study of this kind was performed by Bender and Jung during World War II.[2] In summarizing their results these authors believed that they had established three facts: (1) that deviations of the apparent vertical from the objective vertical exceeding 2° are indicative of injury to the frontal or parietal lobes; (2) that lesions of the occipital lobes, even if associated with hemianopsia, do not result in a similarly disturbed perception of verticality; and (3) that the direction of deviation is indicative of the side of injury—clockwise deviation of the apparent vertical from the objective vertical indicates injury to the left hemisphere, and vice versa.

In 1954 Teuber and Mishkin[8] tested 40 veterans who had sustained brain injuries in combat. These investigators could neither confirm Bender's and Jung's finding that the patient's apparent vertical tended to deviate in a direction contralateral to the lesion nor could they find a significant difference between the performance of their patients and the performance of a group of normal control subjects.

In 1955 we studied the perception of verticality in hemiplegic patients and found it to be disturbed.[4] We did not find a relationship between hemispheric involvement and the direction in which the apparent vertical deviated from the objective vertical. In a subsequent study[5] we adopted a variation of

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the verticality test which had been developed by Witkin.[9] In this modified verticality test, subjects adjust a luminous rod to verticality in the presence of disturbing background figures. Under these conditions the performance of hemiplegic patients appeared to be drastically different from the performance of control subjects. This finding suggested diagnostic uses for Witkin's test. In addition, the test promised to have prognostic value; there were indications that it was capable of predicting success in ambulation training of hemiplegic patients. The present report deals with an elaboration of our two earlier studies. The data presented here were obtained from new groups of patients and of control subjects and have not been reported previously.

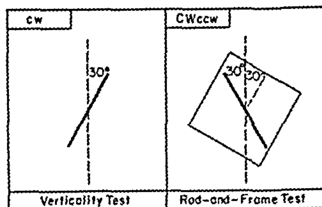


FIG. 1. Schematic representation of two verticality tests used in this study.

DIAGNOSTIC USEFULNESS OF VERTICALITY TESTS

METHOD

Subjects.* One group of hemiplegic patients, 3 groups of other neurologic patients as controls and 2 groups of normal control subjects were tested (see below). All 42 hemiplegic patients included in this study were hospitalized for ambulation training. In each case the hemiplegia was due to a cerebral vascular accident. The control patients had neurologic involvements other than hemiplegia. Included were 11 paraplegics, 9 quadriplegics, 11 patients with multiple sclerosis, and 6 patients with Parkinson's disease. The 50 elderly normal control subjects were tested in a settlement for the aged. None of these elderly control subjects had a history of a major stroke, although the possibility was not excluded that some of them had suffered "little strokes"[1] which went unnoticed.

Apparatus and Procedure. All subjects (Ss) were given two darkroom tests: the traditional *verticality* test, and Witkin's *rod-and-frame* test. In both tests Ss looked at a short luminous rod (20 × 1.5 cm.) which was placed at a distance of 200 cm. from them (Fig. 1). The mid-point of the rod was attached at right angles to the horizontal shaft of a slow speed (0.2 rpm) reversible motor in such a way as to permit rotation of the rod in the frontoparallel plane of S.

* Some of the neurologic control patients were tested through the courtesy of the Medical Service of the V.A. Hospital in Cleveland. All elderly normals were tested at the Golden Age Center, 2320 East 30th, Cleveland. We would like to thank the staff of the Center for their extraordinary cooperation and help.

RESULTS OF VERTICALITY TESTS

Group	Number	Age Mean	Age S.D.	Error Scores in Degrees: Verticality Mean	Verticality S.D.	Rod & Frame Mean	Rod & Frame S.D.
Hemiplegic patients	42	62.8	10.5	4.6	3.7	14.1	12.6
College students	24	20.0	1.0*	1.3	0.6	1.9	0.9
Elderly normals	50	73.2	6.0	3.3	2.0	5.6	5.4
Spinal cord patients	20	32.4	12.1	2.0	0.9	2.8	1.5
Multiple sclerosis patients	11	41.6	16.4	2.5	1.4	4.2	3.2
Parkinson patients	6	62.5	16.4	4.8	1.6	4.3	1.6

* The age of college students was not recorded. The values tabulated above are estimates.

S controlled the clockwise and the counterclockwise rotation of the test rod by means of an electric switch. The task of S was to rotate the rod until it appeared vertical to him. When S was satisfied that the rod was vertical, he stopped it, and the experimenter (E) measured how many degrees the rod deviated from objective vertical. S was not informed of how well or how poorly he performed on the test.

The verticality test consisted of two conditions: condition cw, in which at the beginning of a trial the test rod was turned by E 30° clockwise (cw) from vertical, and condition ccw in which the test rod was placed initially 30° counterclockwise from vertical.

In the rod-and-frame test a luminous outline square (25 × 25 cm.) was placed around the rod in such a way that the center point of the square and the mid-point of the rod coincided (Fig. 1). This test consisted of 4 conditions: in 2 conditions the square was tilted 30° clockwise (CW); in the 2 other conditions it was tilted 30° counterclockwise (CCW). These 2 conditions of frame tilt were combined with the 2 conditions of rod tilt resulting in the 4 conditions of the test (CWcw, CWccw, CCWcw and CCWccw). The 2 conditions of the verticality test were given twice to all Ss; the 4 conditions of the rod-and-frame test, once.

At the beginning of each testing session, before turning off the lights, E made sure that S knew what was meant by verticality ("straight up and down"). He tested ability of S to operate the electric switch and to rotate the rod into a vertical position while everything in the room was in full view. Before the rod-and-frame test E demonstrated to S that the position of the frame would be changed during the experiment, and he stressed that the frame was put there in order to confuse S. E made it quite clear to S that he should pay no attention to the frame while adjusting the rod to verticality. If during the testing session E had any doubts whether S understood what was expected of him, testing was interrupted, the room was lighted, and S was requested to perform the task with the lights on. Whenever adequate communication could not be established between E and S, testing was discontinued, and data obtained from such Ss were discarded.

The testing procedure had to be modified with the 9 control patients with quadriplegia, and with some of the patients with Parkinson's disease. The quadriplegic patients were tested while lying in a prone position on their roll beds. As these patients were unable to operate the switch which activated the reversible motor, E operated the switch for them following their verbal instructions. Some of the patients with Parkinson's disease also had difficulties with the switch. Whenever necessary E helped these patients. Testing was discontinued for patients who could neither operate the switch nor give intelligible verbal instructions to E.

Results

The main quantitative results of this study can be summarized as follows:

1. Patients with left hemiplegia (N=21) did not differ from patients with right hemiplegia (N=21). Therefore, the data obtained from both diagnostic subgroups were pooled.

2. We did not find a systematic relationship between hemispheric involvement and the direction in which adjustments of the test rod deviated from objective vertical.

Because of this finding the direction of deviation was disregarded in further computations, and only the amount of deviation was considered. For example, a 10° clockwise deviation of the test rod from vertical was treated the same as a 10° counterclockwise deviation, and both constituted an error of 10°. Two error scores representing the average error of adjustment for each of the 2 tests were computed for each S.

3. On both tests the mean error of adjustment increased as a function of age, as shown in Figure 2. A clear age trend is discernible. The older the group tested, the

larger its mean error score (see also Table 1). As will be seen from Figure 2, the mean error score of hemiplegic patients conformed to this general age trend only on the verticality test. On the rod-and-frame test the mean error score of hemiplegics (14.1°) differed markedly from the score that might be expected on the basis of the advanced age of these patients.

4. All groups of Ss, with the exception of the patients with Parkinson's disease, were influenced significantly by the tilted background of the rod-and-frame test; with the tilted background present their mean error score increased. However, this increase was relatively small for the control groups, it was very large for the hemiplegic patients (Fig. 2 and Table 1).

5. In order to achieve an age match between neurologic control patients and the hemiplegic patients, data for only 15 of the neurologic control subjects (3 patients with spinal cord injuries, 6 patients with multiple sclerosis and 6 patients with Parkinson's disease) were included with the data of only 30 hemiplegics in Figure 3. Data for neurologic controls below 40 years of age, and data for hemiplegics older than 70 years have been left out. The resulting neurologic control

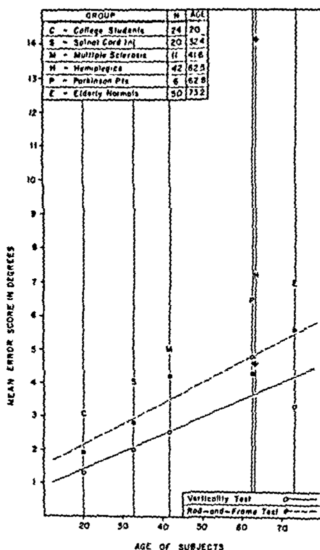


FIG. 2. Relation of age to performance in two verticality tests. In computing the slope and the position of the two lines of best fit, only the mean scores for the 5 control groups were used

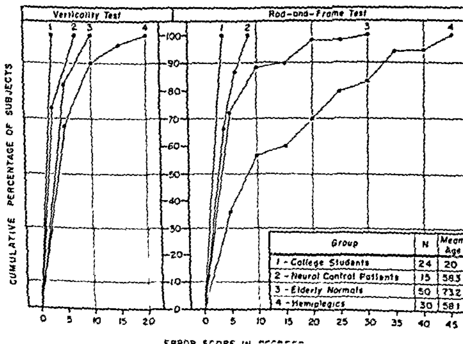


FIG. 3. Percentage of subjects having error scores larger and smaller than any selected error score; for example, on the rod-and-frame test 63 per cent of the hemiplegic patients had error

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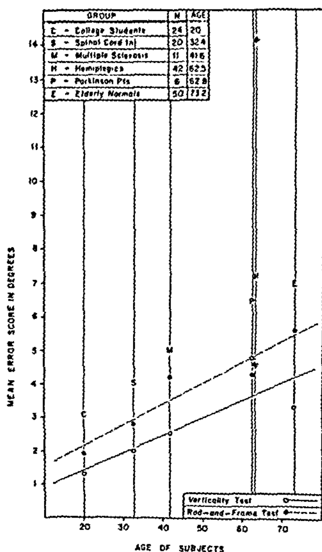


Fig. 2. Relation of age to performance in two verticality tests. In computing the slope and the position of the two lines of best fit, only the mean scores for the 5 control groups were used.

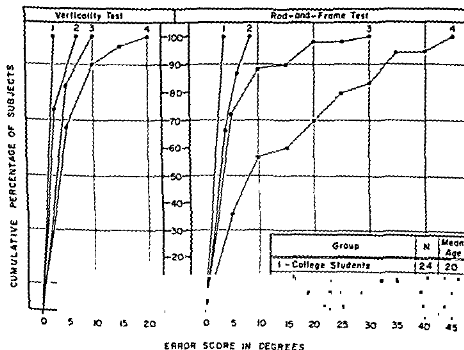


Fig. 3. Percentage of subjects having error scores larger and smaller than any selected error score; for example, on the rod-and-frame test 63 per cent of the hemiplegic patients had error scores larger than 5°.

group had a mean age of 58.3 years (range: 45 to 86 years), and the group of hemiplegic patients had a mean age of 58.1 years (range: 42 to 70 years).

Inspection of Figure 3 shows that the range of error scores is wider for the rod-and-frame test than for the verticality test. This was true of all the groups of subjects. However, the increase in range of error under the influence of the tilted background figure was quite drastic for the group of hemiplegic patients. Of particular interest is the difference between the performance of the neurologic control patients and the performance of the hemiplegic patients. All neurologic control patients scored within an error range of 8°, while only 53 per cent of the hemiplegics did as well. These two groups of patients were equated with respect to age. Thus the striking difference in their performance cannot be accounted for in terms of age.

Discussion

Various contradictory claims have been made in the past concerning the value of tests of verticality as diagnostic tests for brain injury. In this part of the present study the problem was narrowed to one question: can tests of verticality discriminate between hemiplegic patients on the one hand and normal control subjects and patients with neurologic involvement other than hemiplegia on the other hand? We used 2 tests of verticality. One of them was the traditional verticality test described above. The results obtained with this test will be discussed first.

The data presented above clearly indicate the low discriminatory power of the traditional verticality test. Performance on this test is strongly influenced by the age of the testee (Fig 2). The difference between hemiplegic patients and control subjects shown in Figure 3 can be explained, at least in part, in terms of this age variable. Ninety per cent of the hemiplegic patients scored within the error range of a normal elderly control group. The difference between the performance of hemiplegics and the performance of control subjects, with the patients matched in age, is so small as to be useless from a diagnostic point of view.

The second verticality test used in this study, Witkin's rod-and-frame test, seems to hold more promise as a diagnostic tool. Using an error score of 10° as cut-off point we found that 105 (95%) of the 111 control subjects scored below that point, while 18 (42%) of 42 hemiplegic patients scored above it. The 6 elderly control subjects with error scores larger than 10° were 67, 68, 73, 77, 78 and 79 years old, respectively; and the possibility was not ruled out that some or all of them had suffered minor strokes which they did not report, or of which they were not aware.

Error scores up to 10° are relatively common and do not have any diagnostic significance. On the other hand, error scores larger than 10° appear to be diagnostic of brain pathology due to cerebral vascular accidents. Errors of this magnitude did not occur among our 37 neurologic control patients but were found in more than 40 per cent of the hemiplegics. It may be added that within the hemiplegic group patients with a history of more than one cerebral vascular accident performed significantly ($P = .004$) worse on this test than patients who had suffered only one stroke.

PROGNOSTIC VALUE OF VERTICALITY TESTS

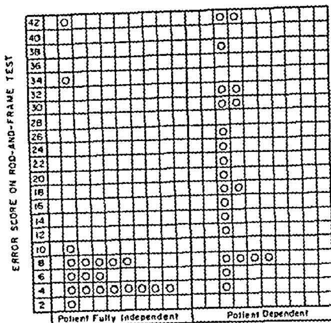
In an earlier study[5] we observed a relationship between performance on the rod-and-frame test and ambulation. Hemiplegic patients with a large error score on the rod-and-frame test appeared to benefit less from rehabilitation training than patients scoring within a normal range of error. This observation was subjected to further test in this part of the present study.

Method

Two sets of data were obtained and correlated. the perceptual data presented

above, and ratings of the patient's success in rehabilitation training. The perceptual data were collected while the 42 hemiplegic patients included in this study were in rehabilitation training. The rehabilitation data were taken from hospital records.

Each hemiplegic patient admitted to the department of physical medicine and rehabilitation of Highland View Hospital is rated at the beginning and at the conclusion of rehabilitation training. The following 5 ratings are being used: (1) bed-bound; (2) wheel-chair-bound, partially independent in activities of daily living; (3) wheel-chair-bound, completely independent in activities of daily living; (4) ambulatory, if guided, assisted or supervised; (5) ambulatory, completely independent. These ratings form part of the hospital record of each patient and were done in complete independence and without knowledge of the present study. We obtained the ratings from the hospital records long after the perceptual testing. Only the discharge ratings were used, and each patient was assigned to one of two groups: the "fully independent" comprising 20 patients with a discharge rating of 5, and the "partially dependent" comprising 22 patients with discharge ratings 1 to 4. These two groups were compared by us as to their performance on the rod-and-frame test.



SUCCESS OF REHABILITATION TRAINING

Fig. 4. Relation of success of rehabilitation training to performance on rod-and-frame test. Each of the 42 rings represents 1 hemiplegic patient.

Results

Our findings are presented in Figure 4. Of the 20 patients who achieved full independence (rehabilitation rating 5) only 2 had error scores larger than 10°. On the other hand 16 of the 24 patients who did not achieve full independence (rehabilitation rating 1 to 4) had error scores larger than 10°. This finding is highly significant statistically ($Chi^2 = 14.34$, $P < .001$).

Discussion

The preceding section shows that, within a group of hemiplegic patients, low-scoring patients differ from high-scoring patients. In general, patients with error scores smaller that 10° are more likely to benefit from rehabilitation training than patients with error scores larger than 10°. However, success in rehabilitation is predicted less well by a low score than lack of success is predicted by a large error score (Fig. 4).

Our findings raise many questions for which, at present, there are no answers. We do not know why the perceptual disturbance described in this paper occurs with such frequency among hemiplegic patients, nor do we know why chances for optimal recovery are against those hemiplegics who manifest the disturbance. Much more will have to be learned about space perception in general, and perception of verticality in particular, before answers to these questions can be given. At this point any interpretation of our results remains in the realm of speculation, and the following attempt at interpretation cannot claim to go far beyond it. Elsewhere,[3] we have presented evidence which suggests that visual space perception is tied to processes of voluntary innervation.

As a matter of fact, we started the present research because we were led to believe, on the basis of other evidence, that patients *with disturbed voluntary innervation processes* should show abnormalities in the area of space perception. The present findings appear to fit into this picture. If, as we believe, abnormal space perception is a reflection of grossly disturbed processes of voluntary innervation, then it would seem to follow that hemiplegic patients perform*ing inadequately* on a space perceptual task would lack potential required for optimal recovery.

Very few clinical tests, taken singly, are diagnostic of disease or are prognostic for chances for recovery. No clinician would base his decisions on the outcome of a single test. Results of many tests are considered and weighed against each other before diagnostic conclusions are drawn and therapeutic decisions are made. We do not suggest that the perceptual test described in this paper, taken by itself, has major diagnostic or prognostic significance. *Judiciously* used as part of a battery of tests it may prove to have some clinical usefulness.

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Le Perception de Verticalitate in Patientes Hemiplegic, con Referentia al Problema del Rehabilitation

Summario in Interlingua

Es describite un test in que le subjecto, *in un camera obscurate, effectua per control* a distantia le rotation de un virga luminose circa su puncto central usque le virga, in le opinion del subjecto, se trova in position vertical. In iste test de verticalitate le performance del patientes hemiplegic non differe frappantemente ab le performance de subjectos de controlo de etates appareate. Tamen, si le adjustation del virga experimental debe esser effectuate contra un fundo de objectos inclinate, le resultatos producite per circa 40 pro cento del patientes hemiplegic devia per plus que 10 grados ab le *linea vertical objective*. Errores de iste magnitude non esseva trovate in tests du paraplegicos, quadriplegicos, patientes con sclerosis multiple, o patientes con morbo de Parkinson. Esseva constatate que patientes hemiplegic con un si pronunciate anormalitate del perception de verticalitate beneficia minus extensemente ab mesuras de rehabilitation que patientes hemiplegic qui produceva deviationes intra le margines de error de normal subjectos de controlo.

12

Use and Abuse of Physical Therapy in Rehabilitation

JOHN MCM. MENNELL, M.A., M.B., B. CHIR., D.M.R.E. (Cantab.)

It is an often forgotten fact that without the practitioner of physical medicine and the modalities of physical therapy there would be few or no rehabilitation programs today. Without physical restoration there can scarcely be vocational rehabilitation.

Yet the physicians who practice rehabilitation today tend to be trained less and less in the diagnostic phases of physical medicine and less and less in the use of the modalities of physical therapy. Rather, they tend to accept the diagnoses of specialists in affiliated fields and to prescribe the use of machine therapy, supplemented by exercise programs of one sort or another, exclusively. Thus the practice of physical medicine tends more and more to be left to the practice of the physical therapist.

It is fortunate, therefore, that in most schools of physical therapy instruction of the students is in the hands of older therapists, experienced in the use of all physical therapy modalities. If the students so trained are deprived of using this knowledge, they will rapidly forget the use of most of these modalities, and in the next 10 to 15 years it may eventuate that student therapists come to be taught nothing but the use of various forms of heat and exercise. Thus, a very large majority of the patients who need them may be deprived of medical and paramedical skills which may be the only treatment modalities that will relieve them of their physical suffering and pain.

It may come as something of a surprise to many to be reminded that physical therapy in its scope includes all of the following modalities of treatment:

1. Mechanical Therapy
   - A. Massage
     - a. Effleurage
     - b. Pétrissage
     - c. Tapotement
     - d. Friction
   - B. Manipulation
   - C. Exercise
     - a. Free
     - b. Active
     - c. Assisted
     - d. Resistive
     - e. Passive
   - D. Traction
2. Heat
   - A. Diathermy
   - B. Short Wave
   - C. Radiant Heat
   - D. Infrared
   - E. Wet Heat
     - a. Local
     - b. General
   - F. Wax
   - G. Hyperpyrexia—Fever therapy
3. Cold
4. Ultrasound
5. Electrotherapy
   - A. Alternating Current
     - a. Faradism
     - b. Sinusoidal

B. Direct Current
   a. Interrupted galvanism
   b. Anodal galvanism
   c. Cathodal galvanism
   d. Drug iontophoresis
6. Heliotherapy
7. Actinotherapy
8. Hydrotherapy
   A. Local
   B. General
9. Supports
10. Occupational Therapy

It will be noted that electromyography has been omitted from the above list. That is because no machine or mechanical device can ever replace clinical examination as a diagnostic tool. A well-trained physician, with the assistance of a well-trained therapist using the faradic and the galvanic currents evoking muscle response, can still give a more accurate diagnosis and prognosis than can a reading of an electromyograph. To substitute a machine for an observing brain constitutes an abuse of physical medicine.

Of the modalities listed let us consider the proper use of those which should commonly be used in physical rehabilitation.

MASSAGE

In prescribing massage the indicated forms must be specified. Effleurage, or stroking, essentially is designed to produce relaxation of muscle, and both directly and reflexly to increase the blood flow through, and the lymph drainage from, the part under treatment. Physiology teaches us that maximum efficiency of muscle contraction can be achieved only after perfect relaxation and that venous return, a prerequisite for the removal of the waste products of metabolism, can be efficient only if muscle action is sufficient That these circulatory effects must be assisted or resisted by the position of an extremity (or, in the case of the back, by postural relaxation), bringing the effects of gravity into play, is too obvious for further comment Light effleurage is often more efficient than heavy effleurage which, indeed, may evoke muscle spasm.

Pétrissage may be considered for convenience as synonymous with kneading of the tissues, though technically the former term denotes picking up the tissues and submitting them to intermittent pressure, while the latter is used for nonspecific, but rhythmic, deep movement of the tissues. Kneading is used for toning up of normal tissue by mechanically increasing the blood flow through it directly, and reflexly by some undetermined, yet real, effect on the tonus of the neuromuscular mechanism. Pétrissage in its pure form is used for revitalizing the skin and the subcutaneous tissue in which nutrition is faulty, for instance, following either prolonged immobilization in plaster or infection. It also has its use in stretching scar tissue, adding efficacy to other forms of treatment later to be discussed. A special and rather gross form of pétrissage is the most efficient method of stretching the iliotibial bands.

One form of pétrissage—skin rolling—is invaluable in the treatment of a specific form of back pain. For some reason the superficial fascia and the skin become adherent to the deeper layers over the vertebrae in the presence of any pathology in the spine. This adherence is a very painful condition. Tightness and tenderness on skin rolling over the spine becomes, then, a very useful diagnostic tool for localizing pathology in the spine. If, in the course of treating the pathology, this adherence is uncorrected, it will become the primary cause of painful joint dysfunction, setting up a vicious cycle of symptoms even after the adequate removal of the original pathology. This adherence can be broken up only by skin rolling.

Tapotement has no place in physical therapy in rehabilitation. Some people believe that tapotement is beneficial to paralyzed muscles. Quite the contrary is the truth. It can only damage muscles with flaccid paralysis and aggravate spasm through eliciting the stretch reflex in spastic paralysis.

Friction massage, achieved by rhythmic fingertip pressure and relaxation, is a most useful form of massage in the treatment of indolent ulcers and in delayed wound healing. Friction over fibrositic deposits in muscle is an integral part of treatment for dispersing what one must presume to be areas of low-grade inflammatory reaction around deposits of metabolic waste products built up in muscles in spasm. It will be remembered that unless a muscle relaxes perfectly, normal contraction cannot occur, and the normal flushing of catabolites will not occur.

The proper prescription of massage in programs of physical treatment is indicated. Its beneficial use is undoubted by those who are familiar with it. It is equally undoubted that massage can easily become a mental addiction and, in fact, massage thoughtlessly prescribed can fix a complaint in the mind of a patient much more easily than physical damage can be removed. Thoughtless prescription of massage is an abuse of a useful modality of physical treatment.

MANIPULATION

Manipulation, by which is meant the restoration of the full range of involuntary movement at a synovial joint, remains the most controversial modality of physical therapy. Yet it is upon the integrity of these involuntary movements—which we call the movements of joint play—that the muscles depend for their ability to carry a joint through its normal voluntary range of movement. The so-called "stretching of a joint" bears no relation to manipulation. In fact, this term as such is meaningless to a thinking physical therapist, and its prescription constitutes a great abuse of physical therapy. Stretching structures around a joint in which movement is impaired—as distinguished from *manipulating* the joint—can only do harm. The overcoming of contractures by turnbuckle casts or cast wedging has no place in physical therapy and lies only in the province of the physician. The breaking of intra-articular adhesions by manipulation also falls only into the physician's province. The restoration, or at least the maintenance, of the movements of joint play falls definitely within the province of the physical therapist. It is a waste of time for the therapist as well as for the patient to attempt to restore voluntary movement to a joint in which any involuntary movement has been lost. The denial of manipulative technics to patients in physical therapy in rehabilitation is one of the greatest abuses in the field.

EXERCISE

Exercise must be prescribed as specifically as any other modality in physical treatment. That muscles cannot move a joint unless the joint is free to move and that muscles cannot be re-educated unless they can function freely are two fundamental truths which it may seem too obvious to mention. Yet they constitute two basic principles of physical therapy which are surprisingly neglected.

The use of free and active exercise regimens requires no comment, except that free exercise denotes unsupervised generalized body activity, while active exercise denotes unsupervised activity of a part of the body.

Assisted exercise must be stressed during the reparative phase of any part of the locomotor system and always should precede active exercise. Muscle fatigue during repair or healing of the muscle, or its neuromuscular mechanism, always will retard healing. Assisted exercise connotes assistance—manually by a therapist, electrically by the use of the faradic current, or mechanically by the use of water, or slings and springs.

Resistive exercises are useful only in producing muscle hypertrophy, and their use in physical therapy in rehabilitation should be limited to the building up of normal muscles which are expected to substitute for useless muscles. Resistive exercise in therapy designed to re-educate muscle in which there has been pathology is dangerous, since it usually contravenes that basic principle of physiology which shows that perfect relaxa-

tion is a prerequisite for physiologic contraction.

Passive exercise has fallen into disrepute, largely because the term is misunderstood. It should be used to mean exercise without function, be it of joint or muscle. Also, because exercise to most people denotes some gross movement, rather than a scarcely appreciable movement, passive exercise too often becomes assisted exercise which is harmful where function is contraindicated. *Passive exercise—a better term would be* passive movement—should be used to prevent adherence of tissue in sepsis or following trauma; it should be used to maintain muscle volume in muscle involved in lower motor neuron paralysis by the use of interrupted galvanism, which will be discussed later.

TRACTION

The use of traction is too big a subject for a paper of this nature. In physical therapy, however, there is little real use for it, except when given intermittently to the cervical spine following trauma, when it is followed by joint stiffness. In effect, then, traction is a method of (1) restoring lost movement and (2) maintaining joint movement without joint function. Thus, traction becomes nonspecific manipulation

HEAT

Whatever may be the intricacies of the physics of heat, in therapy heat is heat. Its efficacy may depend on how deep it penetrates, but wherever it is used in therapeutic doses, it can produce only dilatation of blood vessels, hyperemia and congestion, sweating and relaxation. It must be remembered that congestion may produce muscle spasm; consequently, relaxation may be only transient. It must be remembered also that heat may burn and give rise to pathology, *rather than assisting in its removal. Also, it* must be borne in mind that hyperemia will produce osteoporosis. Prolonged heating may irreversibly alter tissue by cooking Carelessness with wet heat can produce scalding.

Both diathermy and short wave produce a concentrated heat at a depth, but very little superficial heat. Therefore, their dangers are greater than the modalities which produce superficial heat, because the signs of overdosage are invisible.

Heat in any form may be used only with the greatest caution in diseases in which sensory perception is impaired. There is *one absolute contraindication to the use of* diathermy and short wave, namely, osteoporosis. A second contraindication for its use by untrained personnel is the presence of metal in the field.

Diathermy and short wave have three uses in therapy which are often forgotten but have not been improved upon with the passage of years and merit restitution into current therapy. In the treatment of osteomyelitis, where drainage has been instituted, short wave has a remarkable curative effect. In the treatment of gonorrheal arthritis, pelvic diathermy is curative. With special technic, short wave is assistive in the treatment of coronary artery disease, just as its coplanar application is in arterial disease of the limbs. Though only indirectly concerned with physical therapy in rehabilitation, short wave is considered by many to be the treatment of choice in chronic sinusitis, which may be a potent focus of infection in the infective arthritic and rheumatoid group of diseases.

There is little that need be said about the use of the other forms of heat which produce superficial effects—radiant and infrared heat—except that the resulting local congestion must be dispersed by massage if any real benefit is to be had. And the use of wet or dry heat baths to promote the elimination processes in disease by sweating should be remembered.

Wet heat, i.e., hot baths, either local or general, compresses and steam, combine the effects of hydrotherapy (to be discussed later) with heat and inexpert massage. But

to treat a swollen edematous extremity thus will only add to the congestion and edema of the part.

The heat of paraffin wax is sometimes the only thing that makes life tolerable for the rheumatoid arthritic. A hot wax supporting bandage is one of the most comforting and inexpensive forms of support for strained ligaments.

HYPERPYREXIA

Hyperpyrexia, or fever therapy, at low degrees (to 102° F.) is useful for rehabilitation in treating diffuse fibrositis and at high degrees (up to 106° F.) may still be required in generalized gonorrheal arthritis and general paresis of the insane. Since the advent of antibiotic therapy, this modality has necessarily fallen into disuse; but we have all seen these diseases resistant to antibiotics, and therefore, hyperpyrexia should not be forgotten.

COLD

The treatment of acute inflammation and bleeding by cold is mentioned for completeness and speaks for itself.

The use of contrast baths, i.e., alternating hot and cold immersion, produces arteriolar gymnastics and is time honored in the treatment of acute soft-tissue injuries.

ULTRASOUND

Ultrasound in physical therapy has demonstrated its effectiveness so far in two areas. The first is to increase the permeability of a semipermeable membrane, the second is in the softening of fibrous tissue. In a case to which my attention was drawn recently, ultrasound was prescribed for the treatment of a painful neck condition It was administered by an untrained aid who arbitrarily increased the intensity prescribed because the patient did not feel anything. Shortly thereafter, the patient developed paralysis, the diagnosis of which was cavitation in the cervical cord induced by the ultrasound treatment. This unfortunate incident underscores the potential dangers of ultrasound if it is administered by anyone but a trained therapist.

ELECTROTHERAPY

The use of electrotherapy is almost entirely neglected in physical restoration programs; yet, correctly used, it is one of the most efficient forms of treatment available. The potential uses are demonstrated well in the physiology laboratory but tend to be forgotten in the practice of clinical medicine. It is only by the use of hand-surged faradism that the physiologic action of muscle can be imitated. It is only by hand surging that the current can be used to vary the intensity of contraction, allow full relaxation of the muscle and also allow for the refractory period of muscle, the last two being the most important phases of muscle action. The use of automatic surges must fatigue muscle, thereby delaying repair. Of course, too vigorous hand surging will also fatigue muscle and delay repair. The ability to pick out one muscle for treatment by the use of faradism efficiently prevents substitution for it by other stronger muscles. The minimal muscle movement which can be elicited by the faradic current is infinitely smaller than a minimal active muscle movement. Use of a muscle without function can thus be achieved safely, and this prevents adherence of tendons to their sheaths, during the healing phase of tenosynovitis, or of scar tissue to the adjacent layers of muscle fibers in healing of muscle tears. Faradism can be used only when the neuromuscular mechanism is intact. The use of the faradic current of constant intensity between stationary electrodes, the intensity being subtonal, has remarkable pain-relieving properties in bone and joint disease, such as Marie-Strümpel disease and Paget's disease. The reason for the anesthetic effect of faradism is not understood, but it is an undoubted clinical fact.

The use of the galvanic current is manifold. Interrupted galvanism is the only treatment by which muscle volume can be maintained in a denervated muscle, and this only

for about 6 weeks. But to maintain muscle volume while nerve repair is taking place is an important goal in physical restoration therapy.

The use of anodal galvanism in the treatment of recent trauma is twofold. It tends to encourage the flow of edema fluid away from the anode to the cathode, thus producing a rapid diminution of local swelling; and it has a pain-relieving effect.

Treatment by iontophoresis—ionization—is a neglected therapy. The common drugs used in iontophoreses are: salicylates, for their antirheumatic and sedative effect; iodides, for their fibrolytic action; local anesthetics, for the smooth diffusion of their anesthetic effect; zinc, for its coagulating properties; copper, for its fungicidal properties; histamine, for its local circulatory effect; and, more recently, hyaluronidase, for its lysing properties.

Considering that large textbooks have been written on electrotherapy alone, it is obvious that only an indication of its uses can be given in a paper of this sort.

HELIOTHERAPY

Treatment by sunlight has been superseded by actinotherapy in physical treatment, but "artificial sunlight" does not have the beneficial effects of this treatment taken in the open air. The good effects of heliotherapy are lost when, as is fashionable, the aim is to attain a "healthy" suntan, for, of course, there is no better way of preventing the ultraviolet light being absorbed than by an overabundance of skin pigments. In the presence of suntan, heliotherapy can be only a method of heating, and a dangerous one at that. Also a holdover of suntan, into the winter months, may deprive the body of adequate ultraviolet light in winter, thereby contributing to the susceptibility to winter infections.

ACTINOTHERAPY

Except in the treatment of rickets, little use is made of ultraviolet-light therapy. Its bacteriocidal effects are usually remembered in the treatment of paraplegic bed sores, but its effect will certainly be nullified if the sores are not débrided mechanically before its application, as the waves will be absorbed by the superficial wound debris. Too little use is made of the "tonic" effect of ultraviolet light in the debilitated patient, the anemic patient and the patient suffering from osteoporosis. Counterirritation by the use of ultraviolet light in the treatment of deep scars and contusions is most effective.

HYDROTHERAPY

The greatest use of water in rehabilitation programs is the fact that water will remove the effect of gravity from the whole or any part of the body. This allows the use of muscle or joints without function, so often the essential initial phase of re-education in rehabilitation. The presence or the absence of certain elements or salts in the water is of little significance, except that the higher the specific gravity of the water, the more buoyant it is. In other words, salt water is better than fresh water. The presence of sulfur in the water will promote the superficial circulation by surface irritation, and reflexly deep circulation will be enhanced. Sulfur also promotes sweating, which will add efficiency to the eliminating functions of the body through the skin. If the water is hot, the heat will supplement these effects; and if the water is agitated, it will, in effect, give unskilled massage.

The thoughtless use of the whirlpool bath in the treatment of trauma and circulatory diseases of the extremities often does more harm than good, as it produces further congestion in a dependent part. Also, it indicates an empiricism of thought that can only bring disrepute to physical therapy.

SUPPORTS

The use of supports of all kinds must be considered a modality of physical therapy but cannot be detailed here. However, let the dangers of supports never be forgotten

The prescription of support for a weakened muscle can only further weaken the muscle. "Corrective" shoes and "arch supports" never corrected anything. The feet will surely correct the shoes and the supports, and while doing so the feet will be further traumatized. The addition of pressure pads to supports, if they press on muscle, will produce muscle atrophy. The use of elastic and sponge rubber in supports allows for error in their manufacture, and more efficiently supports the patient's morale than any part of his body.

OCCUPATIONAL THERAPY

Occupational therapy must be considered an integral part of physical treatment, and in its broadest sense is vocational rehabilitation. The Woodrow Wilson Rehabilitation Center at Fishersville, Va., is a unique prototype for the best way of combining physical restoration with vocational rehabilitation. There each of the vocational training schools is an ideal occupational therapy department. Therapy in the occupational therapy department is particularly useful for developing and retraining in reciprocal muscle action and for the resumption of whole-limb co-ordinated activity. In rehabilitation, it should be the function of occupational therapy to retrain a patient in the activities of daily living and vocational needs. In upper extremity prosthetic training, occupational therapy is of paramount importance. The prescription of "distractive therapy" is usually an abuse of both the term therapy and of the professional status of the therapist. Unless physical therapy and occupational therapy are integrated, there will be conflicts in aims which will impair the effects of both.

* * *

In general, it must be remembered that no one form of physical therapy can ever be expected to produce any real benefit to a patient. A simple example will be sufficient to point this out. Consider the patient with an infected indolent ulcer of the leg. Whirlpool treatment with warm water may well efficiently débride the ulcer, but it will also tend to débride fresh granulation tissue. It may also produce dependent edema and circulatory stasis, which will produce efficient conditions for the beginning of secondary infection. Ultraviolet light by its bacteriocidal properties may well control the secondary infection, but it can never reach the organisms unless the wound debris is removed. Iontophoresis with hyaluronidase by its lysing action will materially assist in a débridement process but does little if anything by itself to remove the debris. Iontophoresis with zinc will stimulate the formation of granulation tissue and, by coagulation, will protect the new tissue from mechanical destruction. It will do little, if anything, to protect it from bacterial invasion and may even promote bacterial growth by its induced mechanical protection. Epithelialization and marginal granulation will be prevented by cicatrization around the margins of the ulcer. Marginal frictions and pétrissage will help to prevent this cicatrization, thereby enhancing marginal repair. Effleurage with the leg in elevation, and given centripetally, will decrease venous stasis and dependent edema, enhance lymph flow and encourage the arterial blood supply. Support of the vascular channels by the use of a Unna boot between treatments will help to maintain efficient circulation, which controlled exercise will enhance.

Thus, in the efficient treatment of an infected indolent ulcer, hydrotherapy, electrotherapy, heat, actinotherapy, massage, support and exercise therapy all play an important role and require specific prescription. Prescribing any one of these modalities alone offers no hope of materially healing the pathology and, therefore, constitutes an abuse of physiotherapy.

It must also be remembered that any benefit derived from 30 minutes of physical therapy a day will readily be undone unless the principles of the treatment are carried

through by the patient into the other 23½ hours of his day.

The use of treatment by physical means may be time-consuming, but it is time-honored and in the treatment of trauma, locomotor dysfunction and, indeed, in some diseases it has no peer. It is very nice to know how to restore a bodily function after it has been lost, but how much more satisfactory it is to know how to prevent or minimize the loss! This has always been the role of physical therapy in medicine.

There is a great need for education in physical therapy—for doctors to learn its potential and its prescription, and for therapists its application.

The public today, more than ever before, needs and demands physical therapy. Nonphysicians come forth readily to fill this need. Physicians try to fill the need the best they can. The inequality in demand and supply is one of the main causes of the greatest abuse of physical therapy in this country, namely, the operation of physical therapy machines by untrained personnel in quasimedical offices and, unfortunately, in medical offices as well. Sometimes, indeed, a short-wave or ultrasound machine has become as much a necessary concomitance of a doctor's office as a pinball machine is of a bar and a grill, a result for which ethical physicians cannot be blamed. Physical therapy shops, operating under the guise of industrial clinics, and small rehabilitation centers are cropping up all over the country, preying upon the misfortunes of the gullible public and fattening on insurance companies which of necessity must underwrite the treatment costs.

Whereas before the era of rehabilitation, physical therapy was chiefly and rightly used in the treatment of acute short-term disabilities of the locomotor system and also was often used as the treatment of choice in many diseases throughout the different specialty fields of medicine; now it is used chiefly in chronic neuromuscular disease and some geriatric problems. So what used to be a means of restoring patients to their usual normal way of life, economically and quickly, now is more a means of re-educating patients to a less efficient and to some an abnormal way of life, often uneconomically and often very slowly.

Let no one suppose, however, that I deprecate in any way the principles of total vocational rehabilitation for the permanently handicapped, which is one of the greatest steps forward in the practice of the humanities of medicine in this 20th century.

Physical medicine sired rehabilitation as one of its most illustrious progeny. Today, however, the worthy parent is frequently asked to give way to the needs of so-called rehabilitation alone.

Thus the active physical medicine department of a general hospital tends now to devote its energies to (1) the care of the permanently disabled (2) patients who need instruction in the simple use of crutches or (3) patients who have been sent to have their joints "stretched" and their muscles "built up."

A fact which is too often lost sight of today is that patients from all other departments of a general hospital should be referred to the department of physical medicine for that treatment which provides benefits not obtainable elsewhere.

The simplest of random examples will illustrate this: (1) From the medical service, an asthmatic may be referred. Obviously physical therapy cannot *cure* asthma. But the teaching of controlled breathing may well make the difference between a tolerable and an intolerable life for the sufferer. And breathing exercises cannot be efficient if there is joint dysfunction in the costovertebral joints, which impairs chest-wall action. To restore this joint function manipulation is also required. (2) From the department of surgery, patients suffering from peripheral vascular disease may be referred. Massage in its different forms with the affected part elevated, coplanar short-wave therapy and carbachol ionization will

maintain and sometimes actually re-establish circulatory competence in a way that no other form of treatment can. (3) From the ear, nose and throat department requests may be received for treatment for sufferers from chronic sinusitis, in which short-wave treatment is considered by many to be unequaled. (4) From the department of neurology, patients suffering from transient lower motor neuron diseases should be given physical treatment from the onset of their disease. (5) Obstetric patients who are taught prenatal exercises most often have less difficult labor. And postnatal exercises can lessen the incidence of complications which follow weakness of the abdominal muscles and those of the perineum. (6) The scope of remedial and corrective physical therapy in the treatment of mechanical anomalies in the locomotor system of children is manifold. (7) Hyperpyrexia still has a place in the curative treatment of patients attending the department of venereal diseases. (8) The use of the various modalities of physical therapy in the successful treatment of skin diseases is renowned through the centuries.

A generation of doctors is arising who have not been taught the true value of physical therapy in the treatment of disease in general and rehabilitation in particular. Even in the two fields of specialty practice which should be best acquainted with the fullest use of physical treatment, only the most meager use is made of available modalities. There is only a token requirement by the Board of Orthopaedics that the trainee orthopaedist be schooled in physical therapy; and there is no requirement by the Board of Physical Medicine and Rehabilitation for the trainee physiatrist to have any training in orthopaedic diagnosis and treatment.

I realize that criticism of medical education and even ethics is implied by the title of this paper. One cannot talk of abuses in any professional field without such implication. Furthermore, criticism, however well-intentioned, may hurt individuals and causes, and even when proferred constructively may become destructive. Yet it is true, also, that only an individual who is vulnerable can be hurt by criticism; a cause is usually enhanced by criticism which is truly constructive.

There is a multitude of patients suffering from pain and sickness who should be helped by their physicians, but it seems that they find help only by consulting those outside our profession. We also believe that these people are courting risks to life and limb by seeking what we have to call unprofessional aid in their disabilities.

Therefore, I believe that we have a duty to try to improve the therapeutic armamentarium of our profession even at the expense, figuratively and perhaps literally, of a few of our own and maybe even ourselves.

CONCLUSIONS

In concluding, I wish to offer the following constructive suggestions which may help to make the best physical therapy available to more people for the relief from their suffering and the alleviation of their diseases.

1. Rehabilitation must cease to be considered the third stage of medicine. The acutely sick and injured, who should have only temporary disability, are as much in need of rehabilitation methods as are the sufferers from chronic disease and total or permanent partial disability. Physical treatment may well be the treatment of choice in acute problems and will almost invariably cut short convalescence to an economic degree which is scarcely believable to those who are unacquainted with its potentials.

2. By education, the confusion which now exists over the terms rehabilitation, physical medicine and physical therapy must be dispelled. There can be no such person as a specialist in rehabilitation. There *should be* a co-ordinator of rehabilitation and a superintendent or administrator of a *rehabilitation* center. The former may well be a doctor; the latter had far better be an educator. The

doctor co-ordinator must be a competent general practitioner for, to be efficient, he must have more than a passing knowledge of urology, neurology, orthopaedics, and general medicine and surgery, and a competence in psychology as well.

3. The specialist in physical medicine can become an active entity only if he is able to furnish his colleagues with a diagnostic service. Then he must be able to offer, through physical treatment, therapeutic results which, if not better than any other currently available treatment, should be at least as good and as economical. In fact, the specialist in *physical medicine should be an internist* whose competence lies in the differential diagnosis of somatic pain. This, in fact, makes the specialist in physical medicine an orthopaedic physician. Therefore, the training of the physiatrist should be that of the orthopaedist: substituting experience in physical therapy for training in surgery.

4. A direct corollary, then, must be that the training of the young orthopaedist should provide more time for the medical problems of the locomotor systems, this being as vital to the specialty as competence in the treatment of fractures and the performance of surgery. It would be a logical sequel for the American Board of Orthopaedics to offer accreditation in both medical and surgical orthopaedics. It would surely follow that the physician and the surgeon in this specialty would be complementary to each other rather than antagonistic. In the present relationship between the orthopaedist and the physiatrist, this antagonism is too frequently the case often to the detriment of the patient's needs.

5. Physical therapists must take over the management of their own affairs—their ethics, training, examinations and the practice of their profession under the direction of *any* duly licensed physician. Their skills must be available through the prescription of any doctor without the patient's having to pass through the hands of an intermediary physician who may have played no part whatever in the diagnosis of the patient's illness or in the planning of the treatment requested and required. For a physiatrist to approve another doctor's prescription for physical therapy before the patient may receive treatment from a physical therapist is analagous to requiring that a doctor's pharmaceutical prescription should be checked and approved by a pharmacologist before it can be dispensed by a pharmacist. Such a *monopolistic attitude within the profession* must be discouraged by every possible means.

6. Physical and occupational therapists must integrate their aims and efforts for the maximum benefit of their patients. The subspecialty therapists should be absorbed by these main groups.

7. Physicians should use exclusively the services of trained therapists in good standing with their national associations. Doctors must also learn to accept the full responsibility for the treatments which they prescribe.

8. The narrow outlook—that physical therapy is only of use to the permanently disabled—must be eradicated, and all doctors must be taught the wide use of physical therapy in the treatment of disease and learn to prescribe it as readily and as well as they now prescribe the usual pharmacologic remedies.

Only then will physical medicine and physical therapy assume their proper and well-deserved place in the hierarchy of the specialty fields of medicine and therapeutics. Only then will it be possible to write and talk exclusively of their use, rather than of their use and abuse.

Usos e Abusos del Physiotherapia in le Campo del Rehabilitation

Summario in Interlingua

Iste articulo es includite in le presente symposio super le "Rehabilitation" proque, in le opinion del autor, solmente le plus magre uso del disponibile modalitates physiotherapeutic es facite in le currente programmas rehabilitatori. Le causas de iste situation es a vider in defectos in le education general—tanto preparatori como etiam practic—que es offerite in le scholas de medicina. Per consequente il occurre non infrequentemente que le patientes es private del beneficios de un therapia que in lor casos es possibilemente le therapia de election, i.e. un therapia capace a alleviar lor suffrentia o a curar lor maladia.

Proque le publico es conscie del rolo potential de physiotherapia e proque il existe un demanda public pro le tractamento physiotherapeutic, il es natural que le abusos de iste forma de tractamento es frequente e extense. Le natura de ille abusos es signalate, e certe mesuras constructive es recommendate pro lor correction.

Simultaneemente, ben que necessarimente de maniera multo breve, le correcte uso del varie modalitates physiotherapeutic in le rehabilitation es delineate. Attention special es prestate al facto que le uso appropriate del physiotherapia ha un rolo tanto importante in (1) le tractamento del patiente con morbo o lesiones acute como in (2) le tractamento del patiente con invaliditate chronic. Si in le secunde caso le objectivo del physiotherapia rehabilitatori consiste in adjustar le patiente a su incapacitate permanente, su objectivo in le prime caso es restablir le patiente in su forma de vita normal.

Le necessitate del diagnose ante le prescription del therapia es sublineate (ben que iste facto deberea esser evidente). Es etiam indicate le necessitate de un appropriate prescription e le acceptation del responsabilitate pro omne su detalios del parte de ille qui redige lo.

Le hic offerite conception del medicina physic e del physiotherapia es plus large que lo que es communmente acceptate in le medicina de nostre dies.

13

Problems in the Rehabilitation of the Injured Worker and His Restoration to Gainful Employment

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Nothing is of more serious import to the average working man than the loss of earning capacity due to an occupational accident. A serious injury with prolonged disability has far-reaching effects not only on the man himself but also on his family. It is natural, therefore, that the disabled worker should look to his physician for that treatment which will restore his earning power and to society for the right to earn a living, even though some disability may persist. There occur annually in the United States some 2,000,000 occupational accidents, of which, about 100,000 end in some degree of permanent disability. Despite the seriousness of this situation, rehabilitation of the disabled worker has received but scant attention from those who should be most concerned.

Although adequate and competent medical care is of prime importance in physical restoration, it represents only one facet of this complex problem. Labor, management, the insurance carriers, the legal profession and government as represented by state and Federal compensation laws and their administration all play a direct part in the restoration of the disabled to gainful employment. However, none of these groups appears to be fully cognizant of the over-all problem or of the part they must play. All are guilty of practices within their own fields which delay or prohibit the recovery of the injured workman and his return to gainful employment.

Primarily, rehabilitation of the injured worker is the responsibility of the medical profession. Tremendous strides have been made in the past few years in the handling of the acute lesions of trauma, but despite these advances the end-results often leave much to be desired. All too frequently, the physician believes his job to be done with the healing of surgical lesions, adopting the attitude that from then on it is up to the patient to recover any lost function. Unfortunately, rehabilitation does not end with the healing of surgical wounds. Much more must be done, far more than is now appreciated by the medical profession in general. Failure to recognize the importance of surgical and medical after-care in the attainment of the best end-results represents one of the major weaknesses of modern-day medicine. It is time then that we re-evaluated our responsibilities to the injured. We must adopt the concept that our responsibility ends not with the healing of the lesion itself but is continuous throughout the convalescent period and ends only when the patient again returns to gainful employment.

Upon what does successful rehabilitation depend? It depends first upon the extent and the severity of the accident. These are

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factors over which we have no control. It depends, secondly, upon the adequacy of first-aid treatment at the site of accident and upon the competency of transportation to and within the hospital.

Perhaps the most important factor of all is the competence of handling of the acute emergency. When a part has been injured, it is imperative that the exact nature and extent of the injury be recognized. Only upon such knowledge can correct treatment be established, if function is to return to the injured part. If an injured structure is not repaired at the time of the original accident, it must be repaired at a later date. In general, the longer the interval of time between the date of injury and that of eventual repair, the poorer the result. Any attempt to restore function to a part which has not had adequate surgical care will fail. To ensure the maximum restoration of function, physicians must recognize the limitations of their own ability and not hesitate to call in those more capable of treating the acute emergency.

Ranking next in importance is the adequacy of treatment in the convalescent period. Physicians in general, and surgeons in particular, must learn the direct effect such treatment has upon the surgical end-result. The utilization of the minimum amount of splinting to permit early active use of uninvolved muscles and joints is a factor not generally appreciated. Of equal importance is the use of exercise not only for the injured part but also for the body as a whole. How many excellent reductions of a Colles' fracture end disastrously because of swollen and stiff hands, or frozen shoulders due to lack of early active exercise of these uninvolved joints? How many patients confined to bed for weeks are retarded unnecessarily in their ambulation because their general body tone has been allowed to deteriorate due to lack of exercise which could have been given during enforced recumbency? All patients, particularly those who are ambulatory and under domiciliary care, must be placed on those exercises which will restore function to a maximum degree in the shortest possible time. These exercises should include those obtained through work therapy. The patient must be given specific instructions as to how, when and why these exercises should be done. This means scrupulous attention to detail on the part of the physician. Unfortunately, many physicians feel that they have no time for such detailed supervision. However, this is as important an aspect of adequate care as is the treatment of the acute emergency and is, therefore, a necessary task which we must not shirk.

In many instances, physical facilities may not be available, either in the doctor's office or in the patient's home, or the patient may be the type who will do nothing for himself unless constantly supervised. In such cases, the patient should be sent, if possible, to a special center where such facilities and supervision can be given. There is a great demand on the part of many lay groups for the establishment of special rehabilitation centers throughout the country. The need for such facilities, particularly for the seriously injured, cannot be denied. However, the real need is for the doctor to realize that once he has undertaken the care of a patient, his obligations to that patient do not cease until he has been restored to as near normal as is humanly possible. To that end the doctor must learn how to administer the most effective type of after-care or to utilize the services of those individuals or institutions capable of so doing.

Intercurrent medical diseases, such as diabetes, nephritis, anemia and vascular lesions, to name a few, may do much to retard convalescence and are apt to be overlooked. Therefore, it is imperative that all surgical cases which show a delayed or prolonged convalescence be examined by a competent internist to rule out such possible medical complications.

The psychological complications which sometimes arise following injury may assume major proportions in emotionally insecure individuals and may prohibit their rehabilitation to such a degree as to require psychiatric assistance. In most instances, however, depression or a feeling of insecurity is brought on by the loss of income, worry over inability to meet current expenses, to meet mortgage payments, or to keep a child in school. This situation may not appear to be the concern of the physicians; nevertheless, it is a complication of trauma. If the physician has the confidence of the patient, a few moments of frank discussion may do much to relieve the patient of his anxiety. Not infrequently, the physician may have knowledge of how financial aid may be obtained and thus afford the patient some relief from his apprehension.

Often depression may be due to fear of unemployment, either through the loss of a job or inability to return to regular work. If the physician is aware of this fear, a telephone call to the employer may result in the promise of work. In cases in which an individual cannot return to his regular work, and when jobs are frozen by seniority rights, a discussion with management and union representatives may be productive of a promise of work within the patient's capacity.

It may seem to many that this type of social service is not a duty required of the attending physician. However, we must remember that we are doctors and that we are treating sick patients. The psychological effects of trauma are as real and as important to the patient and his recovery as any surgical complication and, therefore, require our attention.

Frequently, injuries are of such extent and severity as to make it immediately obvious to the surgeon that his patient never can return to his regular work. When such an appraisal is made, the patient and his family should be made aware of the fact as soon as it is prudent to do so. Then efforts should be made to contact an agency interested in vocational rehabilitation. Occasionally, such training can be started while the patient is still hospitalized. The sooner such training begins, the sooner the patient will be able to return to some form of gainful employment. It is not fair to the individual to allow him to entertain the hope that eventually he may return to his regular work when he obviously cannot do so.

In 1951, 4,430 persons who were injured on the job* while under workmen's compensation were returned to work under the Federal-state program of vocational rehabilitation. However, the average time lag between injury and referral to the vocational rehabilitation agencies, was 7 years. The economic loss to the patient and the community in these cases was tremendous. There were undoubtedly many factors, some of which will be discussed later, which operated to produce such prolonged disability, but in some cases restoration could have been expedited by more careful medical supervision.

It is obvious that if we are to obtain the best end-results, we must follow our patients much more scrupulously than has been our practice in the past. We must adopt the concept that our responsibility begins with first-aid and ends only when our patients have returned to work. Therefore, we must give attention to the numerous essential details encountered in the after-care period, and we must attack and treat all complications of trauma—psychological as well as physical. The overlooking of any of these details or complications may nullify all previous efforts at treatment and result in permanent disability with its disastrous repercussions.

Even if such detailed medical care were available today, rehabilitation and restoration to gainful employment would still be

* Report to the Chairman, Manpower Policy Committee, Office of Defense Mobilization, by the Task Force on the Handicapped, p 37, Jan 25, 1952.

unattainable for many seriously injured workers, due to the innumerable roadblocks thrown up by our society.

Labor itself, through the exercise of its seniority rights, presents one such obstacle. In a closed shop, every job is frozen; the tenure of employment is determined by the longevity of employment. Those with the longest term of service hold the highest seniority and are, therefore, the last to be laid off in slack times and the first to be rehired. However, seniority applies only to the particular job held. If a man is so injured that he cannot return to his regular work, he is denied employment for other jobs which he could do, because he has no seniority for these jobs. It would seem that labor, through its powers of collective bargaining, could find a method to free some jobs now frozen by seniority rights to be made available to the disabled of their own unions. This could be done by holding certain jobs open as vacancies occur, to be filled by new employees on a temporary basis without seniority rights, from which they could be bumped in the event that the job could be filled by a disabled union worker. Labor is cognizant of the inequities produced by seniority rights and in time will solve this problem of its own creation.

The attitude of some employers toward their own injured employees and the attitude of industry as a whole toward the employment of the physically handicapped constitutes another obstacle to gainful employment. The attitude of some employers toward their employees is that such workers are only essential parts of a machine whose replacement has as yet escaped the efforts of the mechanical engineer. They seem to have little regard for the rights and the dignity of the men they employ. In the event of injury, they pay the employee off and replace him as one would a broken part. Further, they refuse re-employment when recovery has occurred However, most employers are more humane and because of the action of a few, industry as a whole is not to be condemned. In the recent past, management has been subject to much unjust criticism, particularly for failure to employ handicapped individuals. In our present-day economy, with its high cost of production, the margin of profit per unit of manufacture is often measured in fractions of a cent. Management must keep a sharp eye on all items which increase the cost of production if they are to remain active in a competitive field. In some states with unlimited medical care and unlimited compensation benefits, with concomitant unrealistic compensation laws and methods of administration, one of the major items of expense is that of workmen's compensation insurance. In some states, the laws specifically state that the last employer is the one responsible for the injury, regardless of the number of previous contributing accidents under previous employers. It is little wonder then that management will refuse employment to the handicapped or to those with a history of previous injury, fearing the cost to them should another injury occur. The insurance carrier is in part responsible for this attitude, particularly toward the employment of the physically handicapped. Although there is ample evidence to the contrary, many carriers consider the handicapped as poor risks and will discourage their employment with threats of increase in the insurance premiums, should they be employed. Until our compensation laws are modernized, employers will continue to refuse to accept the hazards of employment of handicapped individuals. Thus, the laws which are striving to protect the worker when injured actually deprive him of employment on recovery. Some protection must be afforded employers if disabled workers are to be re-employed. Some measure of relief could be obtained by the expansion of the second-injury-fund statutes to include all injuries. Employers, thus freed of the major cost should permanent total disability develop, would then be more receptive to the employment of the physically handicapped.

The greatest problems encountered in the restoration of the injured worker are presented by the current workmen's compensation acts and their administration. Although adequate and continuous medical care is essential to recovery, it is actually prohibited in many states through the statutory limitation on cost and duration of medical care. In many states, for example, the cost of medical care is limited to $500, and the duration of care from 1 to 3 months. When the United Mine Workers established its rehabilitation program for the restoration of its own disabled members, it was able to collect from the back country several hundred cases of total disability, many of years' duration. Such an accumulation of human derelicts was largely due to the fact that the laws which should have restored the disabled workers to gainful employment had failed to provide even adequate medical care through the statutory limitation as to cost and duration.

In many states there is no provision in the laws for physical or vocational rehabilitation. Disabled workers in need of such services are never rehabilitated, and when their maximum compensation benefits have been received, they have no recourse but dependency upon the rolls of public welfare. In some states, limited provision is made for such care, but no provision is made for the worker's transportation to the institution rendering treatment, or for the maintenance of himself or his family while under treatment. Most state laws require the provision of a prosthesis in case of amputation, but the repair or the replacement of the prosthesis when worn out must be borne by the injured worker. In those states where the laws do provide for physical and vocational rehabilitation, there is apt to be no liaison between these agencies and the industrial accident commission. Consequently, unless such services are procured directly by the patient or his physician; the worker never does receive the services which the laws provide

It should be pointed out that in some states an injured worker is forced to reject any program which would restore him to his highest efficiency. Any existing disability must be accepted, and the worker must return to work even at reduced earning power, because the weekly compensation benefits are fixed at such low levels that they fail to provide for adequate family need. No man with a family can afford to stay long from work in these days of high living cost on a weekly benefit of $35 or less. Yet, such a situation exists in many states.

In those states with more realistic compensation benefits and with laws which provide unlimited medical care, there has been an alarming increase in the cost of workmen's compensation insurance, without any appreciable change in the number of workers rehabilitated or in the quality of their restoration. This is due to the highly legalistic system of handling industrial accidents and to the lack of supervision of medical care. When the compensation laws were established some 40 years ago, there were many types of injury which did indeed end in total permanent disability. Medical science had not developed to the point where it could offer much in the way of physical restoration. Therefore, the laws were developed to compensate the worker for his loss of earning power, usually in the form of a financial award based upon the percentage of anatomic loss. With the progress of medicine and the development of physical and vocational rehabilitation, we no longer see the disabilities of 40 years ago, and it is questionable whether any injury is truly permanently and totally disabling, provided that the injured worker is given every opportunity and has the desire and the fortitude to rehabilitate himself. However, the laws have not kept pace with this progress and continue to ignore the fundamental needs of the injured. Although they have become more liberal, they still attempt to resolve the problems of disability on a basis of scheduled cash award based on anatomic

loss. Instead of attempting to reduce disability, they do, in fact, place a premium upon it. Such a system not only invites legal controversy but also the prolongation of disability and the delay in return to work for financial gain.

Compensation attorneys desirous of obtaining the maximum award with an eye toward their own financial gain are not adverse to the prolongation of disability. Not infrequently, they will advise their clients to discontinue medical care or to change the attending physician to one of their stable; or they will block attempts at physical and vocational rehabilitation and discourage any attempt at return to work when it is to the worker's financial, physical and psychological advantage to do so.

The insurance carrier, on the other hand, has developed stratagems to control cost. Every effort is made to keep medical care within their control. At times, injured workers, upon threat of loss of compensation benefits, are advised to transfer treatment from their own physician to one employed by the insurance company. When the carrier is able to employ a man of outstanding ability, this is often to the worker's advantage, but few carriers have the foresight or are able to procure the services of the best qualified physicians in the community. Therefore, the medical services offered by the carriers are often not the best that the community has to offer.

Carriers will also take every advantage of the compensation laws in order to save expense. Often, the need for specialized medical care, including physical and vocational rehabilitation, is finally recognized, but because of the statutes of limitation as to cost and duration, sufficient funds or time are not available for the completion of such treatment. In such instances, delaying tactics are employed to consume both time and funds beyond which the carrier is no longer liable for the indicated therapy or for the restoration of the injured worker.

Space does not permit a complete discussion of the tactics employed by the insurance carrier or the compensation attorney in the battle for the almighty dollar. The legal controversy which both sides precipitate finally comes for adjudication before the industrial accident authority. The merits of the case are argued by laymen before the lay arbiter. The latter, frequently untrained for his job, confused by the welter of contradictory medical testimony, and being ignorant of the true needs of the injured worker, clears the case from his docket by indemnifying the worker for his functional and anatomic loss and for disfiguring scars. The insurance carrier is relieved of further liability. The attorney receives his commission, and the doctors their fees. The patient gets his award, a sum of money which he spends, and a disability which he keeps. It is axiomatic that litigation is incompatible with rehabilitation. There is little to be said in favor of the methods now employed throughout these United States in the handling of the problems of the disabled worker, a far cry indeed from the method with which the Canadian Provinces handle the situation.

Closely allied to the rising costs of workmen's compensation insurance and to the legal controversies involved in disability is the competency of medical care afforded the average occupational accident. When we speak of occupational accidents, most of us think in terms of the great industrial plants in our larger communities where there is also a concentration of the more highly trained personnel and institutions for the handling of such injuries. Most serious accidents do not occur in such centers but in the smaller communities possessing neither expert personnel nor adequate facilities. Serious injuries treated under these circumstances may not receive the care needed and thus end in severe disability. But such disabilities occur in our larger centers as well, if the attending physicians are not competent to handle the situation and fail to call for expert assistance. It is

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Compensation attorneys desirous of obtaining the maximum award with an eye toward their own financial gain are not adverse to the prolongation of disability. Not infrequently, they will advise their clients to discontinue medical care or to change the attending physician to one of their stable; or they will block attempts at physical and vocational rehabilitation and discourage any attempt at return to work when it is to the worker's financial, physical and psychological advantage to do so.

The insurance carrier, on the other hand, has developed stratagems to control cost. Every effort is made to keep medical care within their control. At times, injured workers, upon threat of loss of compensation benefits, are advised to transfer treatment from their own physician to one employed by the insurance company. When the carrier is able to employ a man of outstanding ability, this is often to the worker's advantage, but few carriers have the foresight or are able to procure the services of the best qualified physicians in the community. Therefore, the medical services offered by the carriers are often not the best that the community has to offer.

Carriers will also take every advantage of the compensation laws in order to save expense. Often, the need for specialized medical care, including physical and vocational rehabilitation, is finally recognized, but because of the statutes of limitation as to cost and duration, sufficient funds or time are not available for the completion of such treatment. In such instances, delaying tactics are employed to consume both time and funds beyond which the carrier is no longer liable for the indicated therapy or for the restoration of the injured worker.

Space does not permit a complete discussion of the tactics employed by the insurance carrier or the compensation attorney in the battle for the almighty dollar. The legal controversy which both sides precipitate finally comes for adjudication before the industrial accident authority. The merits of the case are argued by laymen before the lay arbiter. The latter, frequently untrained for his job, confused by the welter of contradictory medical testimony, and being ignorant of the true needs of the injured worker, clears the case from his docket by indemnifying the worker for his functional and anatomic loss and for disfiguring scars. The insurance carrier is relieved of further liability. The attorney receives his commission, and the doctors their fees. The patient gets his award, a sum of money which he spends, and a disability which he keeps. It is axiomatic that litigation is incompatible with rehabilitation. There is little to be said in favor of the methods now employed throughout these United States in the handling of the problems of the disabled worker, a far cry indeed from the method with which the Canadian Provinces handle the situation.

Closely allied to the rising costs of workmen's compensation insurance and to the legal controversies involved in disability is the competency of medical care afforded the average occupational accident. When we speak of occupational accidents, most of us think in terms of the great industrial plants in our larger communities where there is also a concentration of the more highly trained personnel and institutions for the handling of such injuries. Most serious accidents do not occur in such centers but in the smaller communities possessing neither expert personnel nor adequate facilities. Serious injuries treated under these circumstances may not receive the care needed and thus end in severe disability. But such disabilities occur in our larger centers as well, if the attending physicians are not competent to handle the situation and fail to call for expert assistance. It is

only fair to state that many of the severe disabilities resulting from occupational accidents are the direct result of inexpert medical care. It would seem reasonable, therefore, *that all medical care of occupational* accidents be subject to some sort of medical supervision. This could be done by the creation of panels of impartial medical experts within the compensation system, as recommended by the American College of Surgeons.

The College, through the Committee on Trauma's Subcommittee on Industrial Relations, has been *studying the over-all problem* of rehabilitation of the injured worker for the past 8 years. In this work it has had the invaluable assistance of representatives of two mutual insurance carriers, of the AFL-CIO and the United Mine Workers, and of representatives from the Bureau of Labor Standards of the United States Department of Labor, the Department of Special Services of the United States Public Health Service and the Office of Vocational Rehabilitation of the Department of Health, Welfare and Education. This task force has developed the *Principles for Rehabilitation of the Injured Worker** and the *Operating Principles for a Modern Workmen's Compensation System.†* These principles, approved by the Board of Regents of the College, outline the over-all problem with recommendations for its solution as follows:

Principles for Rehabilitation of the Injured Worker

1. Rehabilitation of the injured worker and his return to gainful employment should be the basic concept in an improved workmen's compensation system. We recognize that the disabled worker wants to be rehabilitated and restored to gainful employment. Settlement of cases on a basis of cash awards alone does not meet the continuing needs of the injured worker and his family.

2. The need for higher standards and broadened benefits in workmen's compensation is recognized. Such standards and benefits should be developed against the background of presently known advances in physical restoration and vocational rehabilitation and adequate standards of individual and family need.

3. Full utilization of all our potential manpower is essential to the welfare and the strength of the country at all times. The discarding of disabled workers is an economic extravagance detrimental to the welfare of our country, wholly aside from the personal effect on the worker and his family. Solution of the problems of trauma requires co-operation, and not competition, between all interested groups and agencies. Therefore, we must improve and expand all activities, public and private, that aid in rehabilitation of the disabled worker.

4. The medical profession should adopt the concept that the responsibilities of the treating physician extend over the entire period of disability to the end that the patient is restored to gainful employment at his highest attainable skill.

5. Rehabilitation and restoration to gainful employment of the injured worker must begin with first aid and continue through the period of disability. In order for a physician to carry out this responsibility, it is essential for him to recognize the total medical problem of the patient in addition to his injury, as well as his personal problems. The physician must bring to bear on these problems all the skills and the disciplines that science and society can offer and utilize all community resources which can assist him in the accomplishment of these objectives.

Operating Principles for a Modern Workmen's Compensation System

1. Before the *Principles for Rehabilitation of the Injured Worker*, as established by the Subcommittee on Industrial Relations of the American College of Surgeons, can be attained, a critical review of the current practices in workmen's compensation, medical care and medical and vocational rehabilitation is required

2. Since rehabilitation of the injured worker and his return to gainful employment is one of the basic concepts of workmen's compensation, changes in the attitude, laws and administration of this system are essential

A. It must become the duty of the compensation agencies to supervise the medical care of workmen's compensation cases with the view:

a To determine the accuracy of the medical diagnosis.

* Bull. Am Coll Surgeons 37:167, 1952.

† *Ibid* · 40:57, 1955.

Problemas in le Rehabilitation de Travaliatores Vulnerate e in lor Restauration a Empleos Remunerabile

Summario in Interlingua

Iste articulo se occupa del problemas incontrate in le rehabilitation de travaliatores vulnerate e in lor restauration a empleos remunerabile. Aspectos del curatura medical es discutite, e suggestiones es facite pro su melioration. Es signalate que le problemas medical constitue solmente un aspecto del situation general. Obstaculos al retorno a empleos remunerabile es representate per le systema del derectos de senioritate inter le empleatos e per le usantias del gerentes in ingagiar empleatos. Iste obstaculos es discutite e etiam le obstaculos representate per le practicas currente del profession legal e del companias de assecuration.

Le plus grande obstaculo al rehabilitation es representate per le leges de compensation pro obreros e lor administration. Le effectos de iste leges super le rehabilitation es discutite. Es presentate suggestiones pro le melioration del leges super le base del Principios Administrative pro un Moderne Lege de Compensation pro Obreros, formulate per le Collegio de Chirurgos American.

14

The Newington Brace for Cerebral Palsy

Russell V. Fuldner, M.D., and Josef Rosenberger, C.O.*

As a form of treatment in cerebral palsy, bracing has yet to meet universal acceptance.[2,5,6] Besides published opinions slighting the value of braces, in practice one frequently encounters a prejudice against prescribing them in "spastic" disease. This attitude, it must be granted, is not groundless. Phelps,[4] a proponent of braces, refers to the danger of aggravating spasticity with braces of poor design. Our own experience has taught us that attempts to brace spastic muscles in correction beyond tolerance succeed only in alienating the patient and frustrating the doctor. Design problems and the simple difficulty of knowing where to lay one's hands on a mechanically sound brace have also militated against full recognition of the value of braces in cerebral palsy. Often the mechanical requirements for effective bracing in a spastic or an athetoid patient are such as to tax the ingenuity of bracemaker and orthopaedist alike.

So far as objections in principle to bracing are concerned, we find dogma difficult to sustain in a condition where progress in the course of treatment is scarcely separable from progress in the course of time. In any event, a well-designed brace has such a variety of uses in cerebral palsy that physicians objecting to one application may perhaps find another quite helpful. This description of an adaptable lower-extremity brace has been prepared in the hope of interesting physicians not presently employing braces in cerebral palsy, as well as others who may wish to compare the brace that they are now using with the Newington model. It is perhaps unnecessary to add that bracing is not in itself a system of treatment and must be co-ordinated with physical therapy and other lines of training. Our approach to habilitation in cerebral palsy is similar in general outline to that described by Deaver.[3]

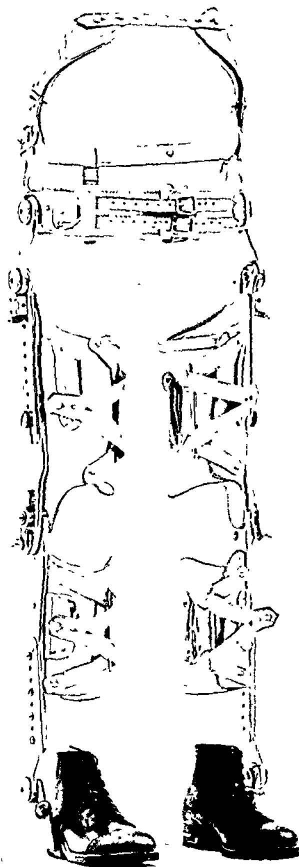
The Newington brace receives its name from the institution where it was developed —The Newington Home and Hospital for Crippled Children, in Newington, Connecticut. The present model results from progressive redesigning of the brace used for meeting the needs of our more severely handicapped children. The only brace available to us 10 years ago, a polio caliper model, was adapted initially to cerebral palsy use by substituting uprights of rigid aluminum alloy for steel and mounting ball bearings in all pivotal joints. After experimenting with various devices to hold the medial thigh uprights apart we attained the more satisfactory solution of eliminating them altogether. This was accomplished by increasing hip-joint diameters and using adequately heavy stock for the lateral uprights. We found that knee caps could be dispensed with if thigh and calf cuffs were of sufficient length. Before discussing the brace in detail a brief note should be made of basic concepts involved in its use.

A NOTE ON GAIT TRAINING

Attainment of serviceable gait should be regarded as a prime goal in the treatment

* New Haven, Conn.

FIG. 1. The Newington brace for cerebral palsy is made of 24 ST4 aluminum with steel double-race ball-bearing joints at pelvic band, hip, knee and ankle. Locks at 180° are provided at the hip and the knee. Pelvic band and leg cuffs are of nylon-treated calfskin with russet leather straps; linings are horsehide. The pelvic band is padded with sponge rubber. A spring steel catch engages a heel slot incorporated in a full-length steel sole plate, permitting ready removal of the shoe. By changing screw positions in the uprights, the brace may be lengthened approximately 6 inches to keep up with the child's growth.



of the cerebral palsied child, ranking in importance with speech training, self-care and the acquisition of school subjects. Indeed, the extent to which these latter accomplishments can be utilized and enjoyed by the patient depends on his ability to get about. While we cannot begin to cover the subject of gait training here, it is pertinent that among a variety of factors determining gait acquisition in cerebral palsy two of fundamental importance are the ability to balance and a sense of independence or confidence on the part of the patient. The child must attain these if he is to walk. To be sure, he must also attain a gait pattern, yet reciprocal motions learned on a plinth are of little use to the child lacking sufficient balance, confidence or control to utilize the motions when upright. Balance and confidence are dynamically acquired, not taught; for the severely involved child they may be painfully slow acquisitions requiring years of effort. In training these children, therefore, it is worth while to introduce lower-extremity bracing early. Braces, unlike walkers, readily accommodate to the patient's body image and facilitate the acquisition of balance, free stance and gait: partly because they bring these attainments within the child's comprehension and mental reach; partly because they aid him to integrate postural and equilibratory reflexes into functionally useful patterns.

BRACE REQUIREMENTS

In treating large groups of cerebral palsied children, a range of lower-extremity

braces and splints is required to meet varying indications—ankle calipers, foot-drop models, night braces, various splints based on the Denis Browne principle. For severe forms of paraplegia and quadriplegia, brace-shop operations can be geared conveniently to a general utility brace meeting the usual needs of this class of patients. In developing the Newington brace, one objective was a single model for both spasticity and athetosis. This was not, in itself, a difficult goal to attain, since basic brace requirements, such as lightness, strength and rigidity, free joint mobility and positive locking, comfort in all positions, ease of application and presentable appearance, are alike in both forms of cerebral palsy. These requirements have been met satisfactorily in our present model, which has been used by 108 patients. Additionally, the brace has other desirable features to be referred to later.

CONSTRUCTION OF THE NEWINGTON BRACE

Except for steel stirrups and small parts, the Newington brace is of aluminum alloy construction throughout (Figs. 1 & 2). The average 6-year-old cerebral palsied child requires a brace weighing approximately 6 pounds; children in the 10- to 14-year-old group demand a brace weighing 8½ pounds (without shoes). As already indicated, scissoring is offset by eliminating the medial uprights of conventional braces and building stress resistance into the lateral uprights and hip joints. Larger hip joints and heavier uprights may be substituted for stock sizes in children with a strong scissoring tendency. (Among our patients, the only one for whom this design proved inadequate in maintaining leg alignment was a ruggedly built young man, nearly 6 feet tall, with unusually severe adductor spasm.) The hip joints of the Newington brace, as well as knee, ankle and pelvic band joints, are of double-race ball-bearing construction, permitting free mobility even in the presence of torsional and lateral strains. As further stress protection of brace joints and uprights, a hinge which allows slight lateral excursion is incorporated in the shoe assembly immediately below the ankle joint (Fig. 3).

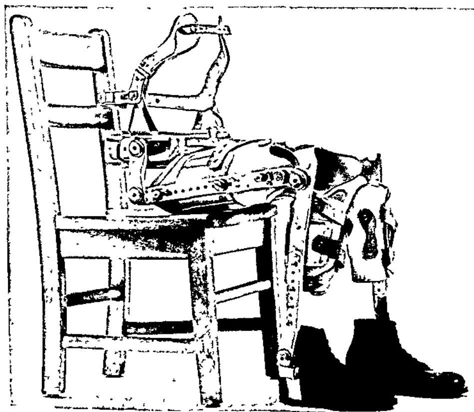


FIG 2. Properly designed, a brace should fit as well in the sitting as in the standing position The hip joints should block at 90° of flexion to offset slump, if they can be locked in this position, as in the Newington brace, trunk balance is aided. 90° knee locks (*not illustrated*) help children with uncontrollable quadriceps overflow to sit comfortably. Observe how posterior hinging of the thigh band permits adaptation to a flat surface, enhancing comfort and fit in the sitting position.

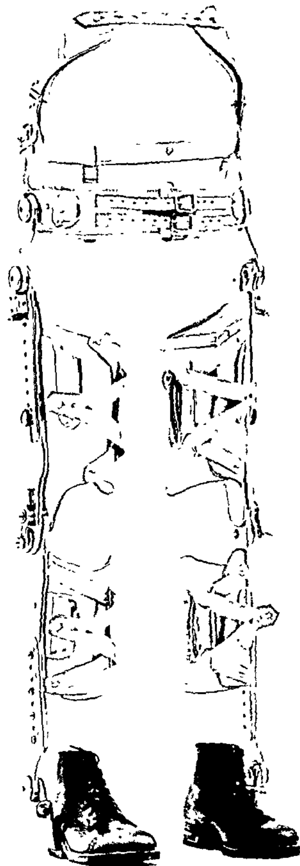


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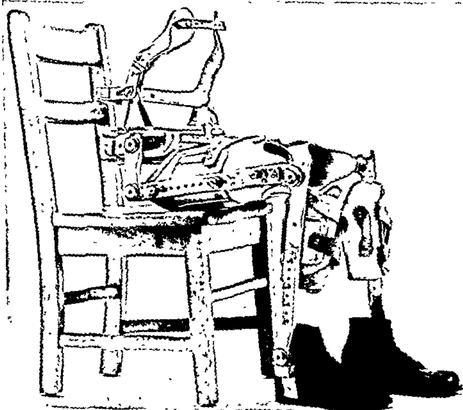


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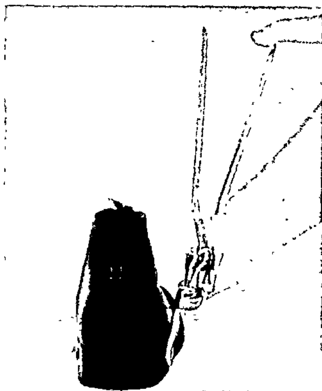


FIG. 3. *Although desirable from the patient's standpoint, lateral rigidity may give rise to brace stress in older patients or those with strong involuntary movements. The double-exposure photograph shows how the hinge below the ankle joint in the Newington brace reduces stress on the hip and the knee joints by allowing lateral play. In any instance where this motion may be detrimental, the hinge can be sealed. Occasionally, a medial as well as a lateral upright is required to control the ankle or the foot or to offset internal rotation of the tibia. In such case the medial upright is attached to the calf band above and an ankle joint below, the hinge being omitted. Braced children require regular check of their leg alignment to guard against the development of tibial rotation.*

A limited swivel at the attachment of the pelvic band to the hip section, permitting flexion of the pelvic band, accommodates flexion of the lumbar spine in sitting, thus obviating the sometimes annoying complaint of pressure from the inferior rim of a pelvic band (Fig. 4). Further construction details are illustrated in Figure 5.

ATTAINMENT OF BALANCE

The trunk unit of the Newington brace (Fig. 6) is not intended for passive support but as a training aid in developing balance. Its design is based on the concept that posture maintenance is essentially reflex in character and that exteroceptive stimuli are of value as reminders of trunk position in children with deficient balance mechanisms. Our knowledge of the reflex basis of pos-

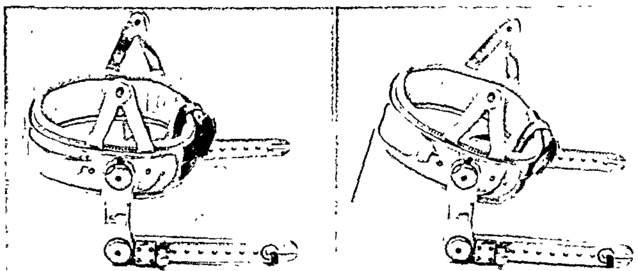


FIG. 4. A limited swivel introduced at the upper end of the hip section allows flexibility in the pelvic band. With flexion of the lumbar spine in sitting, the pelvic band moves in an accommodating arc of approximately 20°. This prevents digging in of the lower rim of the pelvic band posteriorly and permits some freedom of the trunk.

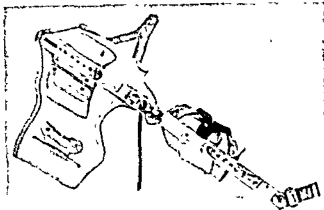


FIG. 5. Simplicity of brace application and removal conserves the therapist's time when the patient receives physical therapy. An easily managed brace also encourages the patient in self-care. The illustrated fastener for thigh and calf bands can be closed or released with one hand. However, laced cuffs are preferable for children with severe spasm or involuntary movement. The flip knee lock can be managed by quadriplegic patients and opened even in the presence of strong hamstring spasm.

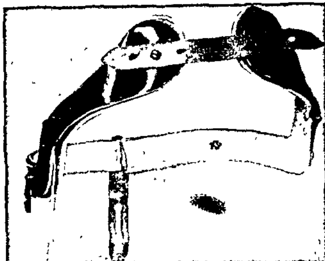


FIG. 6. Balance is a dynamic acquisition, achieved by the severely involved cerebral palsied child only through prolonged and repetitive practice. The conventional back brace, passively slinging the trunk, discourages balance attainment. In the Newington brace the trunk unit has been designed not for support but as a constant reminder of trunk position. The pressure exerted by the pectoral wings on the patient's chest can be controlled by the vertical tie link (illustrated) through a screw attachment to the pelvic band. While ordinarily the trunk unit is mounted as shown in Figure 1, it can be attached in reverse, with the pectoral wings in posterior position, for children with retropulsive movements of the trunk.

tural muscular contraction affords little reason to suppose that these children can be taught balance as a voluntary skill.[1] So far as posture is "learned" at all, the process is one of integrating or modifying postural reflexes on the basis of experience in the upright position. Standing tables and stabilizers are helpful to the child in beginning balance; a trunk support, like that of the Newington brace, advances his concept of free standing, at the same time assisting him to achieve this goal.* The child's active contribution is implicit in the design of the brace: it will not stand up by itself, nor will the pelvic and trunk units maintain an erect carriage. Nevertheless, considerable help is given the child in developing sitting and standing balance by such devices as the hip-joint lock (shown in Fig. 4), which is designed to engage in both the 90° and the 180° positions. These locks, together with those at the knees, simplify initial training through mechanical control of the lower extremities while the patient is developing neck and trunk balance. As improvement in balance is achieved, the hips and the knees are unlocked for increasingly longer training periods.

DISASSEMBLY

In keeping with its primary function as a training aid, the Newington brace can be completely disassembled (Fig. 7). Our objective in physical habilitation is to give the child all the independence that his handicap allows, eventually including independence

* Braces are sometimes objected to on the ground that they "weaken" muscles. Without attempting to discuss this contention, it may be noted that the fit of trunk unit and pelvic band in the Newington brace is sufficiently loose to allow free contraction of paraspinal, chest and abdominal musculature.

from the brace. While, unfortunately, it is impossible to accomplish this latter aim in many severely involved children, the majority are able to omit sections of the brace on a progressive basis over a greater or a lesser period of time. The trunk unit is first omitted during treatment periods, later entirely, to be followed by the pelvic band. These sections are always removed for comfort in bed when the leg sections are used for night splinting.

INDICATIONS FOR THE NEWINGTON BRACE

Full lower-extremity bracing has been an indispensable adjunct in our clinic to treatment of moderate and severe forms of paraplegic and quadriplegic cerebral palsy. While this applies to children for whom the possibility of walking and standing can reasonably be thought to exist, the Newington brace is also useful in chairbound patients with uncontrollable movements or postural slump. In the latter cases a Taylor back brace may be attached to the pelvic band in lieu of the trunk unit. For trainable children, as already mentioned, the brace has served as an integral feature of our physical therapy program in balance and gait work. The brace, by assisting trunk and leg control, correcting torsion and reducing involuntary moven frees the attention of the patient and therapist for the more immediate req ments of reciprocation and crutch hand For parents it is sometimes a revelatio observe how the brace steadies a precai gait or makes progression feasible fc child whose adductor spasm had previc caused hopeless tangling of the legs. haps in the long run it is only in a minori cases that bracing makes the difference tween success and failure in gait attainm but experience gives us reason to bel that a well-designed brace will assist n children to walk sooner and more easily t would otherwise be the case.

Besides these principal indications, Newington brace has a range of secon applications which may be very helpfu certain circumstances. By reducing invo tary movement in the lower half of the bc leg and trunk bracing often gives consi able aid to the occupational therapist wc ing on upper-extremity control in athe children. We have observed repeatedly t these children are enabled to concent more effectively on arm and hand mc ments. The brace should be prescribed young children who cannot otherwise prevented from assuming harmful positic

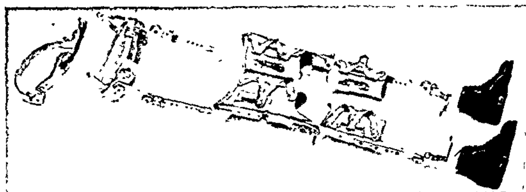


FIG 7. The brace is separated easily into 4 sections. trunk, pelvic and leg units, and shoe assembly. Sectional construction is essential to a brace designed basically for training purposes, since this allows withdrawal of the brace piece by piece as the child is trained in self-control of the part. One hopes, in the usual course of events, to discard successively the trunk, the pelvic and the leg units, thus attaining the objective for which the brace was applied—to enable the child to get along without it

such as a common one of squatting on knees and haunches, with the legs to either side. If long maintained, this posture leads to fixed internal rotation deformity of the femur, not to mention leg and foot deformities. Some children with balance deficit will creep for long periods rather than essay the hazards of walking; here the brace can be applied, initially with the knee joints locked, to prevent creeping and encourage the upright position. We prescribe bracing routinely in early hip subluxation, with the object of preventing increased adductor shortening, femoral torsion and coxa valga. However, to date we have not been able to come to any firm opinion of its value in this connection. The leg sections of the brace, detached and used as night splints (preferably with interchanged shoes, toe caps cut out) are helpful in offsetting contractures of the tendo achillis and the hamstrings.* Postoperatively, when lengthening of these tendons has been performed, the leg sections double as day braces and night splints.

CONCLUSIONS

In our experience, bracing has played an indispensable role in the treatment of cerebral palsied children. Well-designed braces of various models should be extremely helpful to case management in any cerebral palsy treatment center. Braces are as specific in purpose as medication, and should be prescribed with definite objectives in view. The physician assumes responsibility for determining the objectives in each case and prescribing a brace that can reasonably be expected to achieve them. Physician and bracemaker are jointly responsible for the proper design and fitting of the brace, and should ensure that any question arising in the parents' minds regarding the purpose and the application of the brace is answered. In prescribing a major brace in cerebral palsy, such as the Newington brace, it must be remembered that bracing is only one aspect of a multifaceted training program. Institutional supervision often is needed until the brace becomes familiar and its place in the program clearly defined.

* Contractures and fixed deformities in cerebral palsy cannot be corrected by bracing. As a corollary, the *position imposed by a brace should* be attainable passively without discomfort. Disregard of this rule is not infrequent, perhaps accounting for the disrepute of braces in some quarters. A properly designed brace is always comfortable for the wearer; and children, excepting an occasional child with a severe emotional disturbance, do not object to wearing day or night braces that are comfortable

SUMMARY

Among braces of various models used in the treatment of cerebral palsy in children, a lower-extremity brace with pelvic band has been found indispensable in handling the more severe forms of paraplegia and quadriplegia. The Newington brace has been especially designed to provide light yet effective support for the lower extremities and trunk. Sectionally constructed, the brace is also highly useful as a training aid, since it can be left off, part by part, as the child improves in voluntary control. The design and the application of the brace are illustrated in a series of photographs.

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Le Apparato Orthopedic de Newington pro Patientes con Paralyse Cerebral

Summario in Interlingua

In nostre experientia le uso de apparatos orthopedic se ha provate indispensabile in le tractamento de juveniles con paralyse cerebral. Ben-construite apparatos de varie typos possede un alte potential de utilitate in le tractamento del casos vidite a non importa qual centro de therapia pro paralyse cerebral. Le varie apparatos orthopedic es non minus specific in lor objectivos que le varie formas de medication. In prescriber un apparato orthopedic on debe esser guidate per definite objectivos que on vole servir. In omne caso individual, le medico accepta le responsabilitate de determinar le objectivos a attinger e de prescriber le apparato que pare le plus apte a servir le attingimento de illos. Le medico e le fabricante del apparato es junctemente responsabile pro le correcte construction e le precise adjustation del apparato. In plus, illes ha le responsabilitate que omne question que occurre al parentes del patiente con respecto al objectivos e al uso del apparato es completemente clarificate. In prescriber un apparato major in un caso de paralyse cerebral—per exemplo le apparato de Newington—on debe considerar que le application del apparato es solmente un elemento in un complexe programma de trainamento. Un surveliantia professional es frequentemente indispensabile usque le apparato ha devenite un objecto familiar e usque su function in le programma total es clarmente recognoscite.

Inter le apparatos de varie typos usate in le tractamento de juveniles con paralyse cerebral, un apparato pro le extremitates inferior con banda pelvic se ha provate indispensabile in le manipulation del formas plus sever de paraplegia e de quadriplegia. Le apparato de Newington esseva construite specialmente pro provider un non-pesante sed efficace supporto pro le extremitates inferior e le trunco. Illo es construite in sectiones e assi es utile como adjuta de trainamento, proque illo pote esser omittite un parte post le altere in tanto que le patiente meliora su maestria spontanee. Le construction e le installation del apparato es illustrate per un serie de photographias.

15

Woodrow Wilson Rehabilitation Center

ROY M. HOOVER, M.D.*

The Woodrow Wilson Rehabilitation Center is located in the Shenandoah Valley of Virginia, at Fishersville, near the cities of Staunton and Waynesboro. It is owned and operated by the Division of Rehabilitation and Special Education under the State Department of Education. Its primary purpose is the vocational rehabilitation of severely handicapped persons who are unable to get the necessary guidance, therapy and vocational training to fit them for satisfactory employment in any other way. It is a comprehensive center made up of several departments in order to care fully for the various needs of the students; administrative, guidance and students' personnel, medical services and vocational training are included.

The property was originally the Woodrow Wilson Army General Hospital during the Second World War and comprises 400 acres of land and 152 buildings. It was acquired from the Federal Government as "surplus" in 1947 by the State Department of Education for a rehabilitation center and by Augusta County for a technical school and a consolidated high school. The buildings are largely of "semipermanent" construction, brick cased over hollow tile. With one exception, they are all one story in height, connected by enclosed corridors. The buildings have been converted into dormitories, offices, shops, classrooms, guidance and medical facilities, and housing accommodations for staff and personnel. Some additional construction has been necessary, including a number of cottages for staff members and an adequate activities building which includes the guidance, the medical services and the therapy departments, and the infirmary. The accommodations throughout are simple but adequate. Dormitory rooms are arranged for 1 or 2 students to a room. There is a central cafeteria where everyone eats except a few who may be unable to be moved from the infirmary for meals. The students care for their own rooms. The food is simple and nutritious, and corresponds to that of the usual boarding school. The classrooms and the shops emphasize proper equipment rather than expensive housing. The medical services are in simple quarters, but with all necessary equipment and well-trained personnel.

The student body is made up of 350 to 400 students, about 50 per cent of whom are in wheel chairs. Frequently, as many as 25 to 30 states are represented among the student body. During the school year of 1956 to 1957 there were 648 students from Virginia and 257 from 27 other states. Included in this group of students were 123 paraplegics and quadriplegics, 100 amputees, 43 upper extremity and 62 lower extremity, 5 triple. There were 77 polio cases, 71 cerebral palsy cases and 85 injury cases with bone, joint or nerve lesions. There were 102 cases of chronic medical disabilities, including diabetics, cardiacs, epileptics and those with arrested tuberculosis developing work tolerance and receiving training at the same time. There were 23 major congenital defect cases. There were 99 cases of mental retardation and 54 with emotional and psy-

* Roanoke, Va.

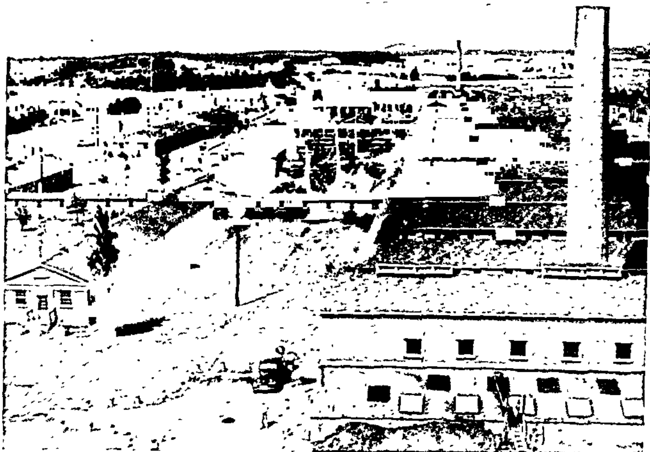


FIG. 1. Woodrow Wilson Rehabilitation Center.

chiatric problems. Since the founding of the Rehabilitation Center, there have been 5,294 students from a total of 36 states and 3 foreign countries.

Funds for operation of all the services and the maintenance and the repair of the facility are derived entirely from fees paid for room, board, medical services and training. There is no state appropriation for operation of the Center. The only funds appropriated are for capital improvement, conversion of facilities, construction of additional buildings and purchase of major equipment. All students are on the same rate, regardless of who pays the fees, with the exception of a slight differential for out-of-state students. A large majority of the students fees are paid for by the Department of Vocational Rehabilitation of the state from which the student comes. About 69 per cent of the students are from Virginia, but many states are represented Expenses may be paid in part or entirely by the family, and it is the policy for the family to pay whatever portion of the expenses that they can. Industrial cases usually are sponsored by the insurance carrier or the employer. A small proportion of the cases are financed by a wide variety of agencies. No special accommodations are provided for "private patients," but they are admitted at the same financial rate and with the same accommodations as others This democratic system of operation without special privileges for anyone because of financial or social standing helps greatly in maintaining good morale in the student body.

In spite of the fact that the institution operates entirely on the fees received for students, the rates are relatively low—in fact, low enough that persons of ordinary means are able to pay their own expenses or the expenses of a member of the family without hardship. This also makes it pos-



FIG. 2. Weaving for a deaf mute.



FIG. 3. Upholstery.

sible for state rehabilitation appropriation funds to take care of many cases at the Center rather than to spend all available funds on a small number. The actual expenses are best illustrated by several case reports. These are typical of cases only requiring training, those requiring therapy and vocational training, and those who require all services including much time in the infirmary.

Case 1. G. A., a 36-year-old man, entered Woodrow Wilson Rehabilitation Center, December, 1953, for barber training. Because of a back injury he had not worked since 1948. In 1950, disk exploration and spine fusion had been done with some improvement but not enough to permit him to return to his former work. He had been a foundry worker, a coal miner, and had worked on a farm and as a day laborer. On entering the Center he was examined by the Center physician, the orthopaedic surgeon and the specialist in physical medicine. Therapy was not considered necessary. On completing his 6 months' training he started work immediately in a barber shop in his home community. Six months after he started working the counselor closed the case with the note that he had not missed a day from work, was very happy, and was fully supporting himself and his family. He had been on welfare since 1948 and had earned nothing during that time. The expense to the Virginia Rehabilitation Service was: Room, board and tuition for 180 days, $540.00; tools and other expenses, $61.60; total cost, $601.60.

Case 2. C. W., a 20-year-old youth, was admitted to the Center in 1955 for training in drafting and for possible prosthetic fitting. At the age of 9 his left arm had been amputated because of a gas gangrene infection in a compound fracture of the forearm. The stump was extremely short and had to be fitted with a shoulder disarticulation prosthesis. He was a high-school graduate and had participated in athletics including football. After receiving his prosthesis, he required 3 weeks' training in occupational therapy to become proficient in its use. He had problems in holding the instruments with his hook. It was found necessary to fit him with an APRL mechanical hand with a wrist flexion unit, which was quite satisfactory. Because of his problem in handling instruments and the resulting slowness in his early training, a 3-month extension of time was necessary. Since completion of his training, he has been employed as a draftsman by an electric



FIG. 4. Resistance exercises to develop strength in the legs.



FIG. 5. Wood working in occupational therapy to mobilize a stiff hand following an industrial accident.

power company. He wears his prosthesis at all times and depends on it in his work. The cost to Vocational Rehabilitation was as follows: Maintenance and training for 360 days, $1,222.00; laundry and incidentals, $120.00; textbooks and tools, $72.00; dental care, $7.00; prosthesis, hook, APRL, hand and cosmetic glove, $670 50; occupational therapy, $52.50; total cost, $2,-144.00

Case 3. R. C., a third-year electrical engineering student, age 20, was injured in an automobile accident, October, 1954 He had immediate paralysis of the lower extremities, the bowels and the bladder. There was compression fracture of the first lumbar vertebra. Laminectomy the following day showed the cord displaced laterally with marked posterior angulation, compression of the conus medullaris with no division of the cord or of the roots. Six weeks after injury he was transferred to the Center, where he continued on a Foster frame in hyperextension. At the time of admission there was some return of sensation. He was given strengthening exercises for his upper extremities and range of motion to the lowers. A cystometrogram indicated beginning return of bladder tone He also received counseling to help with his emotional problems. Sixteen weeks after injury he transferred to a regular hospital bed, and self-care activities were started by occupational therapy; the physical therapy program was stepped up. A training program was arranged in radio and television in order to utilize his previous training and conform to his interests. He started classes on a stretcher but was promoted gradually to a wheel chair as he developed sitting tolerance. Within 3 weeks of getting into a chair he had complete self-care and was transferred to the dormitory. Therapy was increased according to tolerance, and he was fitted with long leg braces and ambulation activities started. One year after admission to the Center he was discharged from therapy. He was then a functional walker using braces and crutches. He was able to walk on smooth or rough terrain, climbed steps with ease and could get in and out of a car. He had a walking tolerance of 2 hours. The wheel chair was used only for distance. He completed his electronic training and before discharge secured a position with a television dealer with a salary—room and board included—and commissions. He started work the day that he completed his course. Expenses at the Center were: Room, board and therapy for 166 days in infirmary, $1,165.00; maintenance training and therapy for 330 days, $1,732.50; maintenance and training for 63 days, $204.75; braces, brace repairs, shoes and crutches, $327.50; wheel chair, cushion and seat board, $198.90; textbooks and tools in training, $41.70; tools necessary to accept the job offer, $455.84; laundry, $80.00; dental care, $4.00; hospitalization for crushing bladder stones, $155.00; total, $3,102.25.

The administration of the Center is under a supervisor who has administrative responsibility for the total program and to whom the heads of the various services are responsible. He works in close co-operation with the director of the Division of Rehabilitation and Special Education, who is at the Center at frequent intervals and devotes a considerable part of his time to its operation. In this way all major policy decisions can be made by personal conference, and much difficulty and delay are avoided. The Administration Department includes the registration and admission office, the record library and the accounting department.

The Department of Guidance and Student Personnel is headed by a director who has over-all supervision of the program and is also active in counseling. In the department

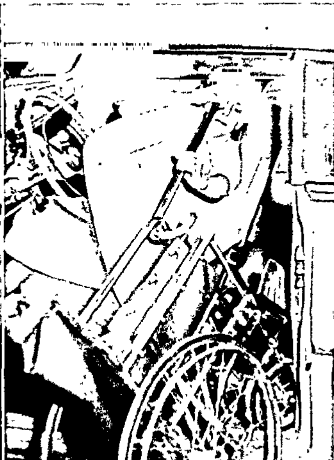



FIG. 6. Paraplegic getting into a car and loading her wheel chair into the car without help.



FIG. 7. Paraplegic training in drafting.

are psychologists who carry out psychological testing and counseling. Guidance counselors follow closely all the activities of the students in school and out They have all had extensive experience as field counselors. They are charged with supervision of the student's training program and his social adjustment, and keep the sponsor or sponsoring agency informed in regard to progress in training and social adjustment. By communication with the student's home rehabilitation counselor, plans are matured for employment

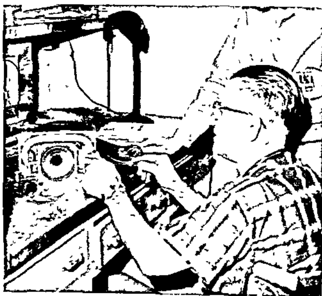


FIG. 8. Paraplegic in radio and television repair.

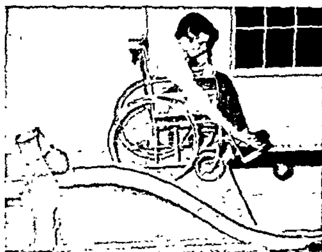


FIG. 9 Paraplegic bowling champion.

for the student when he completes his training period. Any problem which the student may have is the concern of the counselor, whether medical, social, emotional or vocational. If a student is not doing well in his training program, it may be necessary through his counselor, in co-operation with his home rehabilitation counselor, to change into another training field which is better adapted to his abilities.

The dormitory counselors have essentially the same function as the dean of men or dean of women in a college or a preparatory school.

The recreation director plays a very important part in student life. He guides recreational activities, such as wheel-chair basketball, wheel-chair square dancing, bingo parties, amateur theatricals, indoor and outdoor games, picnics and outings, visits to athletic events, etc. Two of the very popular sports are billiards and bowling. It has been found that in these two sports the wheel-chair individual can compete on an equal basis with the students having normal use of all four extremities. A large recreation hall is provided with television, card tables, an area for dancing, and other opportunities for recreation. There is modern equipment for standard movies, and the current films are available.

The library is largely a place of study for those who find it difficult to study in their



FIG. 10. Paraplegic learning to walk wi braces in therapy.

rooms because of interruptions and vis and has reference as well as fiction ma available.

Special education is organized for what its name implies—unusual problen basic education. Not infrequently, a stu may be weak in a subject absolutely ne sary for or certainly helpful in his prop vocation. In this department any neces subject is taught, whether it is arithm English or trigonometry. Because of t disability, the basic education of many the students may have been inadequate, these inadequacies are met by the Dep ment of Special Education. For exampl young man, 22 years of age, because polio had never been able to walk scooted on the floor. After surgery he able to walk with one leg brace. On tes he was found to have excellent possibili in accounting. He had approximately equivalent of a sixth-grade education in s

of the fact that he had never been able to go to school. It was necessary for him to improve his English and arithmetic, and this was carried out in the special education department. In spite of a completely paralyzed left arm, he completed training in business-machine operation and was employed in an office. While employed, he went on with additional training to qualify as a payroll clerk.

A student is usually enrolled with a plan already completed by the local rehabilitation counselor for a program of vocational training and therapy, if therapy is necessary. On completion of his period at the Center, he is returned to his home counselor for placement in employment. If no definite vocational objective has been arrived at, the student may go into a period of vocational evaluation by *the vocational diagnosis unit* composed of a psychologist, a physician and a vocational counselor. Frequently, after thorough testing, examination and study, with the help of physical therapy, occupational therapy, the work-experience shop or any other division of the Center, this group arrives at the most desirable line of training for the student. This period of vocational diagnosis may require from 1 week to several weeks, but frequently makes it possible to place a problem case in a suitable type of training. The results of this evaluation are transmitted to the home counselor, who makes the decision in regard to the placement of the student in such recommended training. His decision takes into consideration the possibilities of placing the student in employment after completion of his training period. The vocational diagnosis study is usually carried out before the student enters for training, and he returns home until a decision is reached in regard to the possibilities of such a training program. The decision is made by the home counselor on the basis of the findings of the vocational diagnosis team and the employment possibilities in his area, and the final plan is written.



FIG. 11. Quadriplegic learning to write with a grasping splint.

The medical services of the Center are *headed up by a director of medical services*, whose responsibilities are administrative, supervisory and general policy making for the department in close co-operation with the supervisor of the Center and the director of the Division of Rehabilitation and Special Education. This position is occupied by an orthopaedic surgeon on a part-time basis. The therapy departments are under the direction and the supervision of a specialist in physical medicine. This physician prescribes in detail the program of therapy required and supervises the progress of all students in therapy, taking care of problems as they arise. The specialist in physical medicine is also an important member of the vocational diagnosis team.

The student health physician is responsible for the general health program of the student body. He has charge of sick call and treats intercurrent illnesses, or if necessary refers students for hospital care or consultation by one of the specialists. He has charge of the medical program of those in training who have medical disabilities such as diabetes, epilepsy, heart ailments or arrested tuberculosis. He cares for the necessary medical or dietary treatment of these students. He is in charge of the infirmary

which cares for intercurrent illnesses requiring bed rest and for the students so severely disabled that temporarily or permanently they require nursing help in self-care and the activities of daily living. The infirmary has 32 beds with 2, 4, 6 and 8 beds per room and is organized with graduate nurses, practical nurses and attendants. An addition is under construction which will increase the bed capacity to 48 beds within a few months. The students requiring hospital care are transferred to one of the near-by hospitals; the infirmary is not considered a hospital. The student health physician is a general practitioner on a part-time basis.

There are a number of consultants in different specialties who come regularly to the Center 1 day each week. There are 2 orthopaedic surgeons who spend a day each week at the Center for evaluation of the many orthopaedic problems as well as brace and prosthesis checking.

A general surgeon with special training and interest in plastic surgery is at the Center 1 or more days each week. One of his very important functions is the care, the cure and the prevention of decubitis ulcers in the large number of severely disabled students. Many paraplegics enter the Center with pressure sores that completely prevent sitting long enough for vocational training. These must be healed and a sitting tolerance developed to allow sitting in classes the required number of hours for training. The possibilities of employment of a paraplegic are no better than his ability to sit in a wheel chair during a working day. Paraplegics and many other very severely handicapped individuals are expected to use a wheel chair for their work. The plan followed is to eliminate pressure sores, using surgery if necessary, and to arrange the seating of the student and his routine of self-care to allow him to be up in his chair as long as necessary for his training and later for his work. It is not enough for vocational rehabilitation for a paraplegic merely to stand and walk in braces; he must be able to sit in his chair as long as his job requires, almost always 8 hours or more, without damage to the skin on which he sits. The surgeon also has the difficult and the unenviable task of differentiating surgical abdomen from nonsurgical abdominal discomforts in individuals who have abnormal or absence of sensation in the abdominal region.

The urologist is kept busy caring for the urologic problems of the paraplegics and other severely disabled students. Examinations and treatments not requiring hospitalization are carried out at the Center. For more complicated procedures the student is transferred to a near-by hospital.

A dentist is in attendance 1 day each week to care for the dental problems of the students. This is especially important in cases in which dental infection appears to be interfering with the recovery of a disabled student.

An ophthalmologist is at the Center each week for necessary eye examinations.

The medical services include physical therapy with a director, 2 supervisors and staff therapists. Facilities are provided for hydrotherapy, using the Hubbard tank, whirlpool baths and hot packs. Under construction is a special therapeutic pool made narrow enough so that only rarely will the therapist be required to be in the water while supervising treatment of a student. The therapeutic pool will be constructed in the form of a T with the two limbs of the T shallow and shaped like Hubbard tanks. The central portion will be deep enough for under-water exercises, using parallel bars if so desired. There is equipment for electrotherapy, short wave, radiant heat, ultra sound and muscle stimulation. There is ample space for therapeutic exercises, gait training and massage. A brace shop and a limb shop are in the therapy area and are operated by a prosthetic company and a brace-making company on a contract basis

The Occupational Therapy Department, in addition to the usual occupational therapy

activities, is responsible for teaching the severely handicapped students self-care and the activities of daily living. Occupational therapy also trains the upper-extremity amputees in the operation and the use of their prosthesis. In this department an excellent determination of work tolerance can be secured that is of special importance in industrial accident cases. Graduated activities are given to increase work tolerance to the employment level. Occupational therapy never is given for diversional purposes only.

A speech therapy department is available for those with speech defects. This is of special importance in cerebral palsy and brain injury cases. The rooms are soundproofed, and tape recording and audiometric technics are used.

An orthopaedic resident from the University of Virginia spends 6 months of his training period at the Center. He examines all students with orthopaedic disabilities on admission and has the opportunity to study a great number of orthopaedic problems, both before and after surgery. He has the opportunity to observe the practical value of orthopaedic operative procedures which may be required or have been carried out previously, many of them a number of years before. He sees many paraplegics and learns their problems and care. He handles many amputees and has a wealth of experience in the prescription and the fitting of prostheses as well as braces.

Students in physical therapy and occupational therapy from training schools in Virginia and other states receive their clinical training in the therapy departments of the Center. They have an opportunity to observe and participate in the rehabilitation training of severely handicapped individuals and to carry out specific treatment of students under careful supervision. Carefully planned lecture training is provided.

A rather extensive juvenile amputee service is maintained in co-operation with the Crippled Children's Bureau Clinics are held at regular intervals for examination, prescription and follow-up care of the child amputees. In spite of the fact that the rehabilitation center is organized primarily for adults, the child amputees are trained in the operation and the care of their prostheses at the Center after they are delivered. There are 33 juvenile amputees under regular periodic supervision, and up to 20 are seen on a clinic day. Of the amputees, the majority are congenital in origin, but there is a very considerable group due to accidents or disease.

Woodrow Wilson Rehabilitation Center is a comprehensive rehabilitation center which, in addition to medical rehabilitation and guidance, provides complete vocational training in many lines of endeavor. Most of the vocational training is secured in the Woodrow Wilson Technical School which is operated by Augusta County with assistance from the State Department of Education. About 90 per cent of the students in the technical school are Rehabilitation Center students. The technical school is operated under a director with a staff of teachers in all departments. Training in the following fields is offered: Business school with its variations, cosmetology, barbering, shoe repair, electric appliance repair, motor rewinding, watch repair, electronics with radio and television repair, drafting, sewing, body and fender repair, automobile painting, automobile mechanics, general mechanics, woodworking, furniture repair and refinishing, upholstering and weaving. In addition, there is on-the-job training in janitorial and maid services, nurses' aids, cooks and bakers, house painting, plumbing, and in the work-experience shop. In the Technical School the classes are arranged with the idea of training the severely handicapped. Wherever necessary, adaptations of seating arrangements and equipment are made to allow those in wheel chairs or wearing braces to carry out their work satisfactorily

However, it is the policy of the school that the work done by handicapped individuals must equal that of nonhandicapped students in order to be acceptable, for they must be trained to compete on an equal basis with nonhandicapped workers. It is considered that a handicapped worker should secure and hold his job on the basis of his ability, not his disability. In the school, there is no hesitation about training an individual for a phase of work which he is able to do if employment is possible in such a special line, even though other phases of the job are not feasible for an individual with such a handicap. In this way the technical school is quite understanding in regard to the problems involved in rehabilitation of the severely disabled and is quite co-operative. A few of the training courses are directly under the Rehabilitation Center and not operated by the Technical School.

With the administration of the Center, the Guidance Department, the Department of Medical Services, including physical therapy, occupational therapy, and speech therapy, and other medical services along with the Technical School all co-operating toward one end, it is possible to secure the complete rehabilitation of a large number of very severely handicapped individuals. The case studies presented show that this is accomplished at a modest financial expenditure.

Centro de Rehabilitation Woodrow Wilson

Summario in Interlingua

Le Centro de Rehabilitation Woodrow Wilson es un instituto de character comprehensive que functiona sub le direction del Division de Rehabilitation del Stato de Virginia. Illo es locate a Fisherville, Virginia, ubi illo occupa un establimento que esseva un Hospital General del Fortias Armate durante le Secunde Guerra Mundial. Illo functiona in conjunction con le Schola Technic Woodrow Wilson que es le proprietate del Contato Augusta. Le edificios original ha essite reconstruite como dormitorios, bureaus, officinas, classes, installationes medical, e quartieros pro le personal.

Le Centro es mantenite sin appropriationes statal pro sia que sia con le exception de installationes capital. Omne le costos de servicio e mantenentia es coperite per pagamentos de studentes pro pension e nutrimento, tractamento medical, e trainamento. Le tarifa es moderate.

Le servicios offerite include servicios de direction e consultation. Le servicios medical coperi hygiene, therapia physic, therapia occupational, e therapia del parola, con ben equipate departimentos e un experte personal. Consulentes medical es in residentia o visita le Centro a intervallos regular pro objectivos de tractamento o surveliantia.

Trainamento vocational es offerite in un extense varietate de campos. Illo pote esser initiate durante que le rehabilitation physic es ancora in progresso. Le disposition e organisation del equipamento e del classes permitte le participation de individuos con sever grados de invaliditate.

Per cooperar intimemente con le consulente de rehabilitation vocational al domicilio del pupillos, le Centro aspira a coordinar le trainamento vocational con le possibilitates de empleo future. Le Centro non considera su servicio como completate usque illo include le mediation de un appropriate empleo e usque le handicappato es ben adjustate a su occupation.

SECTION II

GENERAL ORTHOPAEDICS

16

The Early Diagnosis and Treatment of Fat Embolism

GARRETT PIPKIN, M.D.*

Recent work on fat embolism has removed it from the limbo of long neglect. The existence of the syndrome is no longer subject to debate. It has now been defined, its incidence established, and its mechanism reasonably well demonstrated; means of confirming its diagnosis are available; and principles of treatment are emerging.

Peltier[8] defines fat embolism as probable when fat globules of 10 to 15 micra can be demonstrated in the circulating blood. Recently, Musselman and his co-workers[4] demonstrated that there was enough fat in the femur of an animal to kill it; that fat embolism might be expected in about one half of all persons who were injured moderately or severely; and that significant symptoms would develop in at least one-third of patients with fat embolism.

Since the percentage of cases called "fat embolism" by clinicians is much lower than this, there must be some discrepancy between points of view There is. The research chemist now is able to diagnose morbidity due to abnormal circulating fat within minutes after injury occurs. Clinicians have been waiting until patients died to establish the diagnosis. Differences in standards lead to such contradictory statements as those from Kuntscher,[14] "Fat embolism is the most common complication of medullary nailing," and from The Seminar on Medullary Nailing of the American Academy of Orthopaedic Surgeons,[14] "Fat embolism did not occur." In the latter report, the very next paragraph states, "Nearly all medullary nailings develop an unexplained postoperative fever . . . Thirty-two other complications occurred." This convenient catchall undoubtedly includes some of the results of fat embolism such as cardiac failure, pneumonia, cerebral apoplexy, suspected tetany, subdural hematomas not found by trephining, convulsions and deaths for which an adequate postmortem was not performed.

Obviously, clarification is in order so that we may all be talking about the same thing. The phenomena of fat embolism may be broken down into the following phases: (1) Traumatic lipemia; (2) shock (mechanical); (3) clinical fat embolism (chemical); and (4) death or recovery. These phases represent a morbid process set up by injury and the body's effort to restore equilibrium. Each has its signposts and timetable that may be read by the discerning (Fig. 1).

The traumatic or surgical insult may be a major one in which bone spicules, as well as bone marrow fat, can be demonstrated in pathologic specimens of the lungs, or it may be microtrauma such as results from differential solubility of fat in nitrogen. Men in decompression chambers (high altitude and caisson) have been shown to have fatal fat emboli when the nitrogen bubbled off too fast, leaving the less soluble fat behind.[12] This is why the U.S. Air Force is interested in this entire problem and why obese men are not used as high-altitude fliers.

* Kansas City, Mo

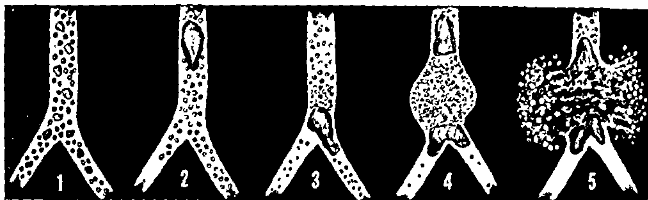


FIG. 1. A concept of fat embolism. (1) Normal alimentary fat measures 5 to 7 micra. (2) Chylons from embolism measure 10 to 15 micra (traumatic lipemia). (3) Ameboid block. (4) Mechanical obstruction (shock). (5) Lipase hydrolysis and chemical toxicity (clinical fat embolism).

Circulating fat globules normally measure 5 to 7 micra. Such globules pass readily through normal capillary beds. Injury gives fat access to the venous circulation. An unknown factor from injury or a hydraulic pressure change causes the fat to congeal into globules measuring 10 to 15 micra—potential troublemakers. These larger globules can be demonstrated within minutes after injury by the research chemist and "occur to some degree in almost all cases of fracture or operation on the bone."[6] In *the absence of specific symptoms, this stage* is designated "traumatic lipemia."

Eventually these large chylons of 10 to 15 micra must try to pass through the capillary bed of the lungs where the narrower limits measure only 10 micra. Blockage results (Fig. 1). Scuderi[7] points out that this is not a true embolus but an ameboid-type block. The fat globules approach an intersection whose lumen is narrower than the globule. Given time, the globule will elongate so as to pass the saddle slowly. Circulation is slowed temporarily but not stopped. (Scuderi states that the phenomena may be studied at will in the capillary web of the *foot of a frog injected with neutral fat.) If* traffic accelerates, the next fat globule arrives before the first clears, and mechanical obstruction results (Fig. 1, part 3). When the process is sudden and widespread, occlusion of the terminal arterioles produces a state of shock. A state of shock also potentiates further mechanical fat embolism.[10,11] The pulmonary artery pressure increases. If the increased work demanded of the right side of the heart is not compensated for, right heart failure and death result.

Autopsies show dilation of the right side of the heart, with thinning of the wall of the ventricle. The lungs are moist, slightly heavier than usual, and anemic. Histologically, the arterioles are plugged with fat. Alveoli are clear (Fig. 2, *top*). Our obser*vations confirm previous reports.*[6,7,16] These conditions may be produced in rabbits by the injection of lethal doses of neutral fat.[6]

When the process is less acute, or the stage of shock has been stabilized successfully, either spontaneously or by treatment, the morbid process may pass on to the chemical phase. The serum lipase value rises.[6] There is hydrolysis of the neutral fat into free fatty acids, which are 7 times more toxic than neutral fat.[7] Capillary leakage results in petechial hemorrhages. Thus, lipase hydrolysis of neutral fat results in a chemical insult responsible for the cyclic disturbances called "clinical fat embolism." The mechanism is self-perpetuating until death results or the body establishes lipase equilibrium again.

Peltier[6] states that

> the latent period between bone injury and the development of the classic clinical signs and

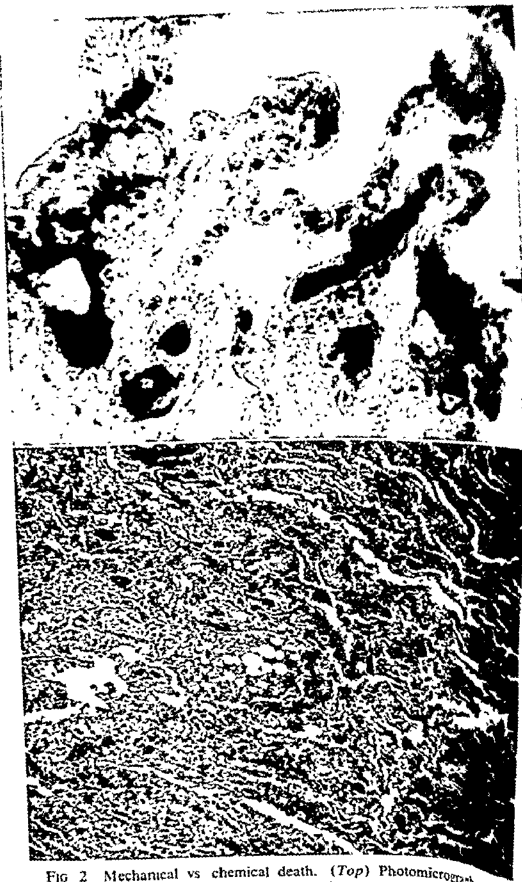


FIG 2 Mechanical vs chemical death. (*Top*) Photomicrograph of [illegible] from patient dying early shows massive pulmonary arterial block [illegible] alveoli. (Love & Stryker. Ann Int Med. 46:342) Cause of death [illegible] of right side of heart (*Bottom*) Photomicrograph of tissue from [illegible] on sixth day after trauma (Case 4) So-called wet red lung shows [illegible] exudate blocking alveoli Death was caused by anoxemia.

in those cases on which data are being collected "for the record." The advantages of a hemoglobin value determination over urinary fat determination are that no special measures are required for collection of the sample, human error is less, and the time element is a matter of minutes. Most important of all, a hemoglobin value determination gives positive information regarding the status of the patient, whereas a negative urinary fat test is without value. Thus, usually, the stages of shock and clinical fat embolism can be differentiated by the determination of the patient's blood pressure and hemoglobin value. *Shock by definition is loss of vessel permeability resulting in hemoconcentration.*[5] The blood pressure falls, the hemoglobin value tends to become elevated, and the red cell volume as determined by the hematocrit rises. *Clinical fat embolism is a hemodilution with increased intravascular space.*[15] Blood pressure rises; hemoglobin, erythrocyte and red cell volume values drop. Erythrocytes remain the same size. Frequently, this fall in hemoglobin value enables one to distinguish between postoperative fat embolism and surgical sepsis (Fig. 4).

Most unfortunately, the clinical signs by which a diagnosis of fat embolism usually is made are in reality "antemortem" signs. For when the chemical phase has existed sufficiently long to produce recognizable petechial hemorrhages in the skin, mucous membranes, conjunctiva and eyegrounds, the patient is in the fourth to the sixth day of morbidity and probably beyond hope of treatment. The surgeon should sharpen his diagnostic acumen to prevent the development of this stage.

Death or Recovery

If death does not result by the sixth or the seventh day after trauma, the morbid

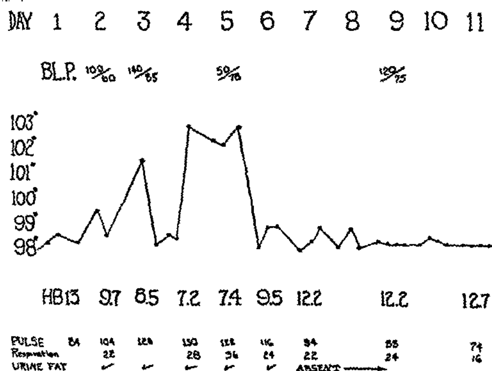


FIG. 3 Hemoglobin values in relation to temperature variations in a clinical case of fat embolism with spontaneous recovery.

process reverses itself, usually by crisis (Figs. 3, 5 and 6). The evening before the patient's temperature may have been 103° F. and the patient may have been irrational, with signs and findings of pneumonia. In the morning he awakens mentally clear, with normal temperature and subsiding pulse. What happens at this particular stage has been poorly studied. Is this crisis only resolving pneumonia? Or does it represent a profound change in the enzyme system, now returning to normal? Our limited observations of cases of closed femoral fractures in adults indicate that hemoglobin values turn

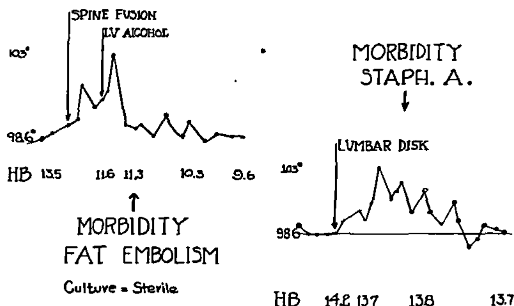


FIG 4. Contrasted temperature charts from a surgical case of fat embolism and from one of surgical sepsis. Hemoglobin values indicated morbid trend 24 hours before cultures did and aided surgeon in determining proper course of treatment.

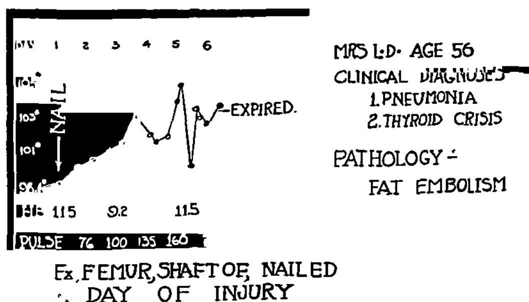


FIG. 5. Fatal outcome in case of closed fracture nailed 3½ hours after injury. Low hemoglobin value on admission was disregarded since patient appeared otherwise to be in excellent condition (Case 4).

upward at this point spontaneously. In one case this turn upward was a gram in 18 hours. Other observers confirm this. Our present interpretation of these findings is that the lung is "unsludging" itself.

TREATMENT

Successful methods of treatment of fat embolism have been recorded in the literature for over 20 years,[1,2] but they have been overlooked or not applied intelligently. In most cases, nature provides a margin of safety of 48 to 72 hours from the time of injury until critical symptoms begin. It is in this period that much can be done. The rationale of treatment is as follows:

Prevention of Entrance of Fat into the Blood Stream

Careful handling of injuries is required to prevent fat from entering the blood stream. For several days following trauma, it is hazardous to transport the patient from one hospital to another, or even from the fracture ward to the x-ray room in the same hospital (Cases 1, 2 & 3). Tourniquets should be used during operative procedures wherever possible.[12] Elevation of injured limbs has practical value, as fat tends to float to the top of the shaft and intravasation becomes less likely.[6,15]

Solvents

Although many fat solvents have been advocated, only alcohol has been shown to have clinical value. In 1933, Hermann[1] demonstrated the protective effects against experimental fat embolism of an alcohol-dextrose solution administered intravenously. Maximum protection was afforded by 3 injections 12 hours apart. The first injection was started as soon after the chemical insult as practical. In view of the

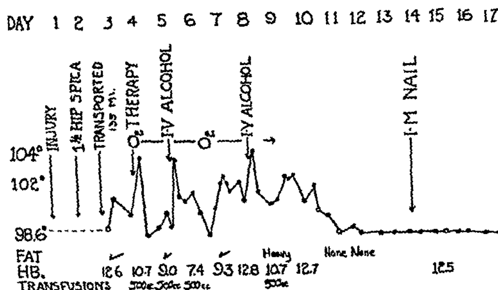


Fig. 6. Established case of fat embolism, showing fall in hemoglobin values and response to treatment with oxygen, intravenous alcohol-dextrose solution and transfusions (Case 5). Nailing postponed until fourteenth day after trauma.

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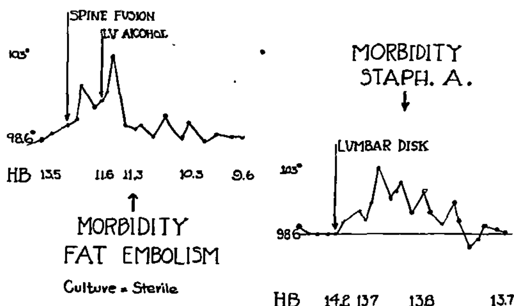


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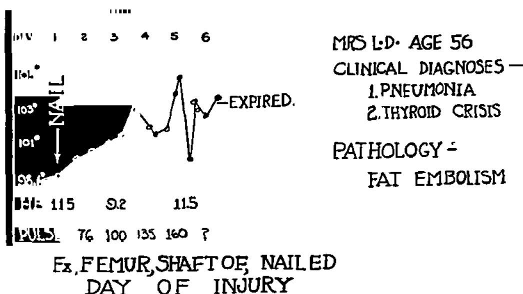


Fig 5 Fatal outcome in case of closed fracture nailed 3½ hours after injury. Low hemoglobin value on admission was disregarded since patient appeared otherwise to be in excellent condition (Case 4).

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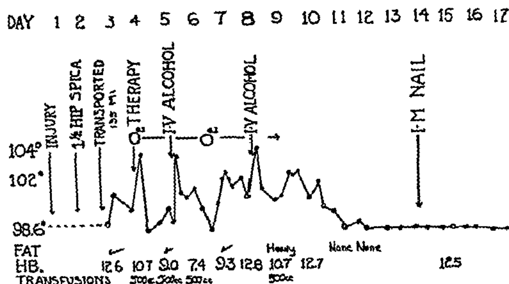


Fig 6. Established case of fat embolism, showing fall in hemoglobin values and response to treatment with oxygen, intravenous alcohol-dextrose solution and transfusions (Case 5) Nailing postponed until fourteenth day after trauma.

now well-established high incidence of fat *embolism, alcohol should be administered* after all moderate and severe injuries. It certainly should be given during all nailing operations, and is of benefit even as late as the fourth or the fifth day when a chest plate shows an established "snow storm." The alcohol-dextrose solution advised is now supplied in bottles containing 1,000 cc. of 5 per cent alcohol in 5 per cent glucose. This amount of alcohol is equivalent to 3 ozs. of 90 proof whisky. This dosage is recommended for a 200-lb. man. A 100-lb. female is given 500 cc.

Oxygen Therapy

Oxygen therapy in fat embolism has a *sound experimental basis, as well as an* established clinical background.

One school of physiology believes that the endothelial lining of capillaries continues inviolate so long as it is adequately supplied by oxygen.[8] It is only when it is deprived of the protective "grease coat" of oxygen that the vessel becomes vulnerable and the fat globules adhere. Inasmuch as fat embolism is ameboid in character in the earlier phases, the oxygen surface tension of the capillary bed can easily determine the outcome in any given case.

*Once the chemical syndrome is estab*lished, the surgeon is faced with a race against time, since the condition usually is fatal or else reverses itself spontaneously about the sixth day. Each petechial hemorrhage is the focal point of an anemic infarct, the extent of which may well be limited by an adequate supply of oxygen to the cross circulation. In fact, it has been reported[3] that the neurologic symptoms of *some patients could be eliminated or re*newed by alternately supplying and withdrawing oxygen

Transfusions

The use of blood transfusions in the stage of shock (mechanical phase) is too well established to require comment.

In moderate and severe cases, about 25 per cent of the circulating hemoglobin sludges, mostly in the lung. This brings up the possibility of "overtransfusing," that is, *assuming that the patient's condition stabi*lizes, of ending up with a higher hemoglobin value than prior to injury. Our clinical experience favors giving transfusions as the need is indicated by periodic hemoglobin value determinations. This view has recent experimental support.[5]

Selection of Cases for Operative Procedures

It is obvious from the preceding discussion that temperature, pulse and blood-pressure determinations do not adequately determine an injured patient's status. Ideally, medullary nailing procedures should be postponed until the serum-lipase value ap*proximates normal. Since serum-lipase* determinations are no longer routine in general hospitals, a practical solution of the problem is obtained by following the hemoglobin values.

The Moral. Do not operate on a patient when the hemoglobin value is falling, and the hemoglobin value determination *should be made the morning of the intended operative procedure*, not 12 hours previously.

Whether or not medullary nailing operations can be performed safely on patients with closed fractures under an umbrella of alcohol and oxygen remains to be established. Ether and chloroform, which are equally good fat solvents, supposedly increase the incidence of clinical fat embolism when used as anesthetics.

APPLICATION OF GENERAL *PRINCIPLES TO SPECIFIC PHASES*

Traumatic Lipemia

The physician should assume that traumatic lipemia will develop in all cases of moderate and severe injuries Splinting and elevation of the extremity should be carried out. Transportation of patients should be

avoided, particularly of those with closed fracture of the femur, the tibia and the chest. *This includes transportation to the x-ray room and back.* Frequent hemoglobin determinations should be made, as well as serum-lipase determinations, if practical.

Shock

In the phase of shock, these principles should be followed: splint and elevate; transfuse; infuse with 5 per cent alcohol and dextrose solution; administer oxygen, preferably in a closed system; and digitalize rapidly in right-sided heart failure.

Clinical Fat Embolism

The onset of clinical fat embolism is preceded by a rapid and otherwise unexplained fall in hemoglobin value. This phenomenon is cyclic, with peaks in the late afternoon and night. An uninformed nurse or house doctor may overlook important signs. From the second through the sixth day after trauma the floor nurse should be asked to telephone the physician's office or residence evening reports on temperature, pulse, respiration and sensorium of patients with closed major fractures. Oxygen, alcohol and transfusions should be given as soon as a significant fall in hemoglobin value and spiking temperature are observed. The amount of alcohol-dextrose solution to be given, as well as its composition, has already been discussed. We prefer to give oxygen therapy through a closed system such as the Bennett respirator. In our experience, it is rare for more than two people in each hospital to know where the Bennett respirator is kept and how to use it intelligently. Both of these people will probably be home in bed when a crisis occurs. We recommend that each physician become familiar with the location of the Bennett respirator in his hospital, as well as the general details of its use. Again, remember that transportation to a recovery room can be hazardous.

A minor complication from the use of the Bennett respirator has been hyperventilation and tetany sufficient to require intravenous calcium gluconate for relief. Rational patients using a respirator should be instructed to breathe freely and easily at their own normal rate.

Nailing operations should be delayed until a rise in hemoglobin value has been established. Research institutions may prefer a falling serum-lipase value for this criterion.

Post-Traumatic Deaths

The physician should insist on adequate postmortem examinations and see that careful fat stains are prepared on at least the lungs and the brain. Do not be an institution that "has never had a death from fat embolism." Such do not exist.

Prophylactic Measures Against Fat Embolism

The following measures are useful in prophylaxis against fat embolism: (1) Use of a pneumatic tourniquet; (2) use of oxygen during anesthesia and through the recovery period; (3) use of a combination of spinal anesthesia and supplemental intravenous alcohol; and (4) anticipation of trouble by making hemoglobin determinations on the *first and the third days after trauma* or surgery.

Case Presentations

As examples of errors in management, our own fatal cases of fat embolism are presented below, together with a short series of severe cases in which fatalities might well have been expected but recovery was brought about by the above-described treatment. No case of fat embolism has been posted on our service since we instituted these methods of treatment in 1954.

Group 1. Errors of Transportation

Case 1. F. C., male, age 27. Sustained skull and chest injuries plus fractures of both femurs Rallied apparently in a small-town hospital and was approved by telephone consultation for *transportation by ambulance 150 miles on*

mesme provide un margine de securitate de inter 48 e 72 horas a partir del trauma usque al disveloppamento de symptomas critic. Il es durante iste intervallo que multo pote esser complite. Le temperatura, le pulso, le respiration, e le pression sanguinee del patiente non provide necessarimente un accurate reflexion de su stato. Un rapide reduction del valor de hemoglobina, si non alteremente explicabile, debe esser considerate como le effecto de embolia grassose, e le therapia debe esser instituite. Si tosto que le syndrome es establite, le chirurgo se trova in un concurso con le tempore, proque le condition es usualmente letal ante le sexte die o se reverte durante ille intervallo. In plure casos le factores decisive pare haber essite le administration de oxygeno, de solution de dextrosa in alcohol per via intravenose, e de transfusiones.

17

The Frederick Thompson Hip Prosthesis

LOUIS W. BRECK, M.D., MORTON H. LEONARD, M.D.,
AND MARIO PALAFOX, M.D.*

Since the first reports by the Judet brothers, of France, concerning the use of a femoral head replacement prosthesis a little over a decade ago, orthopaedic surgeons have come a long way. The short-stemmed plastic device of Judet had many disadvantages; as a matter of fact, at best it was only fairly satisfactory. However, from it have evolved several satisfactory hip prostheses. Since 1953 the authors have used one of these exclusively—the Frederick Thompson Vitallium prosthesis—with gratifying results. This chapter is primarily a report of a series of such cases. In addition, basic principles and technics will be discussed.

THE PROSTHESIS

In our opinion, a hip prosthesis should be long stemmed and made of a hard, inert metal. Our personal experience with the Judet prosthesis has been unsatisfactory. An acrylic head breaks, and one of nylon erodes within the acetabulum. A short stem tends to rock downward in the region of the calcar femorale and upward where it penetrates the lateral trochanteric region.

Vitallium seems to be the best metal for a hip prosthesis because it is the most inert of all metals when used in the human body. In all our cases, Vitallium was the metal of which the prosthesis was made. Perhaps stainless steel will work as well, but we have taken the attitude that the more inert the material the better, especially when such a large amount is used.

* El Paso, Texas

It seems to us that Thompson has devised a prosthesis with an excellent shape and very desirable length. The oblong upper part of the shaft affords good stability and offers resistance to wobbling. The shelf that rests against the calcar femorale is adequate (Fig. 1). If the stem were longer, it would increase the danger of a delayed femoral shaft fracture. If shorter, it would be less stable. The lateral aspect of the stem is flat and exerts a diffuse pressure on the femoral cortex. Additional bony reinforcement forms here gradually (Fig. 2). The prosthesis is relatively easy to insert and quite easy to remove.

TECHNIC

Gibson's posterior incision is used. In some cases it is shortened. The patients are operated upon while lying on their side. Usually a T incision is made anterosuperiorly in the capsule. Following removal of the head, the base of the femoral neck is cut to length and shaped carefully. The neck, the trochanteric and the upper-shaft regions are trimmed carefully to receive the prosthesis, a large drill and shaping tools being used. The prosthesis is pushed in manually against slight resistance. Force never is used. In our cases there have been no split femurs following its insertion. We have used blood transfusions at the time of operation and whenever indicated. There have been no untoward results during operation and no deaths immediately after operation from

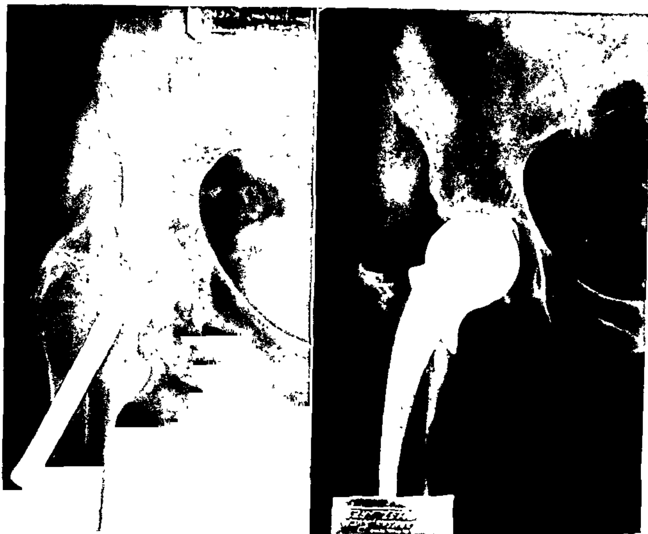


FIG. 1. (*Left*) A Pauwel Type 3 fracture with the nail backed out and the fracture falling apart at 2½ months. (*Right*) Four years after insertion of the Fred Thompson prosthesis. The result was excellent

transfusions. It seems to us that the use of blood has improved our morbidity rates

In almost all cases, Jones's boots and a cross bar have been applied postoperatively and maintained for 3 weeks. This has been done to protect the joint capsule and other soft tissues. The leg on the operated side has been held in slight internal rotation

In a few cases with a long-standing non-union and shortening of the femoral neck, preliminary skeletal traction has been employed to gain length. This has been quite helpful, permitting easier reduction at the time of operation

AMBULATION

In this series, fresh fractures of the neck of the femur are those which had occurred within 2 months. Immediate ambulation has been permitted after removal of the plaster boots. Usually, patients have been in a wheel chair for a few days and then on exercises for a few days. Then they are allowed to be up in an invalid walker. The younger and more able-bodied individuals use crutches The majority have gone from bed into the walker and then gradually have been educated to use one or two canes.

Most of our cases have not found it necessary to use a cane very long after the operation. However, several have continued to use their canes. In the younger group of patients, we have encouraged them to discard their canes. In the older group, they have been allowed to continue to use canes for additional safety. As a matter of fact,



FIG. 2. (*Left*) Severe aseptic necrosis of the head of the femur in a Pauwel Type 3 fracture with first a nonunion and then union following bone grafting. (*Right*) Three years after the insertion of the prosthesis. The end-result was excellent

over half of our cases have discarded their canes completely, choosing to use them only a short time.

In instances where it has been necessary to ream the acetabulum, such patients have not been allowed to bear a significant amount of weight for from 3 to 6 months while the acetabulum was hardening. The few patients who have walked early following reaming have had less satisfactory results.

COMPLICATIONS

The two alarming complications have been dislocations of the prosthesis. In one, the prosthesis was reduced immediately and held longer by the Jones boots. Finally, this case subluxated again, but the patient said that she was comfortable and declined further operation. She was able to walk fairly well in spite of her age, although we classed her case as a failure. In the other case, the patient again underwent operation, and the shallow acetabulum was reamed to a considerable depth. There was no further dislocation in this case. She was a woman in her late 50's with an old Legg-Perthes disease So far the result has in her case been unsatisfactory.

A postoperative sciatic neuritis without paralysis followed in 3 cases. Two of these were due to retractor pressure. This has been carefully avoided since. These were early cases. The third followed an attempt to gain (successfully) too much length at the time of operation. All 3 cases made complete recoveries, although in one it took nearly a year to overcome her severe nerve-trunk symptoms.

Settling of the prosthesis has proven to be a minor complication. In one case settling

prevented a good result. In no case did it progress very far.

Rattling of the prosthesis has not been a major problem. We have had four such cases, and in only one has the patient continued to complain. However, in this case, there was very little pain, and it was classified as a good result.

In another case, a minor fracture of the neck of the femur occurred when the prosthesis was inserted. This was a case of longstanding nonunion. After the operation the patient was kept off weight-bearing for 3 months and then allowed to bear weight gradually. An excellent result followed, and the fracture in the region of the calcar did not prevent a good result.

There have been other complications, most of which have proven to be of minor consequence except those of operative infections. Here, as elsewhere in orthopaedic surgery, the infection produced a bad result.

END-RESULTS

The authors look upon femoral-head replacement in the older age group as a salvage procedure. Accordingly, they believe that evaluations based on degrees of rotation, motion, etc., although useful, do not present results from a practical standpoint. We now project the results from a practical standpoint. We have considered the roentgenographic appearance, the presence or the absence of pain, and the patient's ability to walk as the criteria of greatest value. The patient's opinion is subjective but important. In evaluating many of these patients, one must consider that some are almost bedridden, some are psychotic, and some quite senile. This, of course, influences the functional end-results.

The criteria in the doctor's evaluation are as follows.

Excellent result: No pain; no significant limp; ability to walk without external support.

Fair result: Pain, but not of a disabling or a serious character; significant or marked limp; inability to walk more than a little without external support; a patient markedly improved over preoperative condition.

Poor result: Some pain plus a serious limp plus difficulty in walking; severe pain; inability to get about at all although able previously to do so.

Wobble of the stem of the prosthesis, settling and extraneous calcification did not correlate with our evaluations of the patients. These are listed separately.

Miscellaneous Information

Total number of cases	47
Operative deaths	1
Cases with adequate follow-up evaluation	39
Number of hips:	
Left	20
Right	27
Age of youngest (years)	23
Age of oldest (years)	107
Average (years)	64

End-results According to Patient's Opinion

Number of excellent results	19—49%
Number of fair results	13—33%
Total of excellent and fair results (good)	32—82%
Number of poor results	7—18%

End-results According to Doctor's Opinion

Excellent results	6—15%
Fair results	25—64%
Total of excellent and fair results (good)	31—79%
Poor results	8—21%

Roentgenographic Results

Good	44
Wobble of stem of prosthesis	1
Extraneous calcification (excessive)	1
Settling of prosthesis in femoral head of femur	1

Cases Incapable of Being Evaluated

Lost to follow-up	3
Psychotics	3
Parkinsonism (severe)	1
Advanced senility	2

Surgical Approach

Gibson	46
Anterior	1

Follow-up

Shortest (years)	1.0
Longest (years)	5.5

Postoperative Fixation

Jones's boots	46
None	1

Complications

Dislocations	2— 4%
Sepsis	1— 2%
Thrombophlebitis (without embolization)	1— 2%
Fever, undetermined origin	1— 2%
Embolus	1— 2%
Death	1— 2%
Sciatic neuritis (severe)	1— 2%
Osteomyelitis	1— 2%
Total complications	9—19%

Indications for Operation

Nonunion, fracture femoral neck		18—38.3%
Fresh fractures		11—23.3%
Arthritis:		
Hypertrophic	9	
Rheumatoid	1	
Total		10—21.3%
Aseptic necrosis		4— 9.0%
Old congenital dislocation of hip		2— 4.0%
Unstable pinning		1— 2.0%
Revision of Judet type femoral head replacement		1— 2.0%

COMMENT

A procedure which offers 80 per cent good results is well worth doing, especially when one considers that in most of these cases there is either no alternative or if there is the chances of success are much less. As a whole, we have been pleased with our series. As a salvage procedure it is excellent As an elective surgical procedure, it is only fair. We no longer fear the specter of accumulating a large number of aged human derelicts. Now that we have performed a substantial number of these cases, we feel confident that we can expect a reasonable result.

We have alluded to complications in our paper. One question which proved annoying in the past was, "What does the surgeon do when the prosthesis fails?" In our own hands, the answer has been removal of the prosthesis. We have had to do this only in aged patients. In certain active younger individuals, this still remains a difficult problem. The older group is better off after the prosthesis has been removed than they were with their ununited fracture prior to insertion of the prosthesis.

Considering the number of fractured hips that we see, it seems to us that we have accumulated a rather small series of hip-prosthesis patients. There are probably several reasons for this. We have tended as a whole to be conservative in using prostheses in fresh fractures. If a patient has a somewhat painful hip, we are not prone to recommend surgery. In our opinion, many of our patients with aseptic necrosis of the head of the femur in the aged group have not been uncomfortable enough or disabled enough to justify surgery which would be directed mainly at improving the roentgenogram. In the past, we have not done a large number of fresh fractures. Recently, we have started doing more fresh femoral neck fractures. Those with a Pauwel Type 3 fracture and those that are unstable or cannot be reduced well constitute our principal indications. We have continued to nail most of our fresh fractures. Most of these unite, and some of them, in the aged group result in death. When either result occurs, there is obviously no indication for a hip prosthesis.

In connection with poor results, we have observed that a painful disabled hip is more likely to result in patients with severe hypertrophic arthritis or in those with acetabular sclerosis from a previous aseptic necrosis of the head of the femur.

The authors like the Frederick Thompson prosthesis and use it whenever they believe that it is indicated. It is our impression that, generally speaking, the good types of hip prostheses now available are not being used freely enough by orthopaedic surgeons.

SUMMARY

Forty seven cases are presented in which a Frederick Thompson hip prosthesis has been employed. Statistics are reported.

In approximately 80 per cent of the cases the result has been satisfactory.

The oldest patient was 107, and the average age was 64. A Gibson posterior approach was employed and Jones's plaster boots with a cross bar were used postoperatively in almost all cases.

The indications for operation were as follows: Fresh fractures, 23 per cent; arthritis, 21 per cent; aseptic necrosis of the head of the femur, 9 per cent; others, 47 per cent.

The authors have discussed why they like the Frederick Thompson hip prosthesis, the operative technic and details of after-care, including complications.

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Le Prosthese Coxal de Fred Thompson

Summario in Interlingua

Es presentate un serie de quaranta-septe casos in que le prosthese coxal de Fred Thompson esseva empleate. Es includite statisticas satis detaliate in re ille serie.

Circa 80 pro cento del casos obteneva resultatos satisfactori.

Le plus vetule patiente habeva 107 annos. Le etate medie esseva 64 annos. Le approche posterior de Gibson esseva empleate in le majoritate del casos. Post le operation, bottas de Jones con barra transverse esseva usate quasi sin exception.

Le indicationes pro le operation esseva le sequente: Fracturas fresc in 23 pro cento del casos, arthritis in 21 pro cento, necrosis aseptic del capite femoral in 9 pro cento, e alteres in 47 pro cento.

Le autores discute in alicun detalio proque illes favori le prosthese coxal de Fred Thompson. Illes etiam discute le technica, detalois del post-cura, e le problema del complicationes.

18

Moderately Severe Whiplash Injuries of the Cervical Spine and Their Roentgenologic Diagnosis*

MARTIN S. ABEL, M.D.†

The so-called whiplash injury of the neck is a forced hyperextension and hyperflexion injury. The motion is quite similar to the coiling and the uncoiling of a snapped whip where the head is the weighted end of the whip. This type of injury occurs most frequently in the course of automobile collisions.

The clinical entity of relatively minor whiplash injuries was described rather recently by Gay and Abbott.[6] In their mild cases there was no evidence of fracture in the roentgenographic studies made, and the symptomatology, which was peculiarly long lasting, was attributed to ligamentous strain. Both Gay and Abbott and Braaf and Rosner[4] pointed out the high incidence of herniation of the intervertebral disks subsequent to such injuries, some of which were first observed years later.

Immediate roentgenographic evidence of more serious injury has been presented. Billig[2] demonstrated ligamentous and capsular tears and minimal fractures. Gershon-Cohen *et al.*[7] found avulsion fractures of the posterior spine of C 6 and 7 and T-1 in some of their postaccident patients. They were able to reproduce these lesions in cadavers by a straight forward and backward whiplash of the neck.

Close questioning of patients indicated to us that more damage occurs to the neck when there is a side-to-side component to the whiplash than when the snapping is directly forward and backward. Apparently the maximum injury to those patients involved in accidents occurred when the collision had been partly or wholly from the side or the head had been turned to the side *at the moment* of impact. In fact, in our own experience, this oblique type of whiplash has been by far the more common, and certainly the more likely to be disabling. With forced hyperextension and flexion from anterolateral and posterocon*tralateral*, the neck is much less flexible and the intervertebral disks appear to lose much of their cushioning action. With hyperextension in this manner, the apophyseal joints become

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The experimental work reported here was carried out in the facilities of the Department of Anatomy, University of California School of Medicine, Berkeley.

The author acknowledges gratefully the help given with the anatomic studies by Dr. John b. de C. M Saunders, Dean of the School of Medicine of the University of California (formerly Chairman of the Department of Anatomy); Dr. C. W. Asling, of the Department of Anatomy of the School of Medicine; and Mr. E C. Chin, Jr., student in the School of Medicine. He is also indebted to Miss D. Janson for technical assistance rendered.

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FIG 1. Anatomic studies of the amputated neck of Cadaver A. A to D are the routine anteroposterior, lateral and oblique views, respectively. B is not quite a true lateral. The deep tissues of the neck have been left intact except for the minimal dissection necessary to put wires around the right lamina and transverse process of C-3 and insert lead squares in the fifth and the sixth apophyseal joints on the right.

Note that in the routine views the right lamina of C-3 is never clearly seen free of superimposed structures. On the anteroposterior view the body and the pedicle overlie it. In the lateral view the two laminae are superimposed. In the left posterior oblique, it is overshadowed by the lateral mass; in the right posterior oblique, by the body. In both obliques the lamina is foreshortened, as evidenced by the projection of the wire as a rounded loop.

(Continued on facing page)

weight-bearing, and on the reverse forced hyperflexion there is development of excessive torque and considerable ligamentous pull on the posterolateral elements of the vertebrae.

EXPERIMENTAL PROCEDURE

An attempt was made to reproduce this oblique type of whiplash injury on cadavers and to correlate the findings with known clinical cases. The necks of 6 cadavers were forcibly hyperextended and hyperflexed unilaterally in the following fashion:

The skulls were sectioned and the brains removed. The deep muscular and fascial structures of the neck were left intact except for the minimal amount of localized dissection necessary to place metallic markers on the vertebrae and in the intervertebral joints for roentgenographic studies of the anatomy.

A mallet was placed inside the skull immediately lateral to the foramen magnum and then hit with a 1-pound hammer while the neck was in extension and again while the neck was in flexion. The blows were directed unilaterally in the direction of further extension or flexion. The mallet was used to diffuse the force of the blow and prevent shattering of the skull. By applying the blow in this way we felt that the force then was applied somewhere near the center of gravity of the head, and so we hoped in this way to approximate more closely the clinical conditions of whiplash trauma.

The necks were roentgenographed in routine and special projections before the procedure, between the hyperextension and hyperflexion blows and after the procedure Subsequently, the neck stumps were dissected out and roentgenographed again. Then the soft tissues were removed completely from the vertebrae, and the vertebrae were subjected to careful anatomic study.

The circumstances were reproduced approximately in the Dynamics Laboratory, and the force transmitted through the mallet rather grossly measured utilizing a cathode-ray oscilloscope. The force had a duration of about 20 milliseconds with a peak instantaneous value of about 200 pounds.

Severy, Mathewson and Bechtol[10] state that the load to the head may exceed 100 pounds for rear-end collision not exceeding 15 mph. in their experimental crashes, peak loads of about 150 pounds were recorded in collisions at both 10 and 20 mph. and associated with direct backward hyperextension of the neck. The neck was subjected to this force for an interval of about 50 milliseconds, with a time-force curve quite similar to that recorded by us.

The circumstances of the crash experiments and the forces measured there are obviously not identical with those of the cadaver experiments, but the forces applied are of the same order of magnitude. Moreover, any correction for the differences in the direction of whiplash should tend to make the forces applied more nearly alike. Accordingly, the situations seem to be sufficiently similar to permit of some comparison.

RESULTS

Anatomic Studies

An attempt was made to evaluate various roentgenographic projections and technics

Fig. 1 (*Continued from facing page*)

The right transverse process of C-3 is thrown clear only in the right posterior oblique view.

The lead squares in the apophyseal joints are both seen partly *en face* in the anteroposterior view In each of the other three views, one is seen on edge and the other partly *en face*. Thus, in none of the routine views are both the marked apophyseal joints seen in profile

Note also in B the large defect in the interarticular isthmus of C-7 on the right. This was produced experimentally by the forced hyperextension and hyperflexion. Compare it with the very similar defect in C-7 of Figure 9B, a roentgenogram of a whiplash victim.

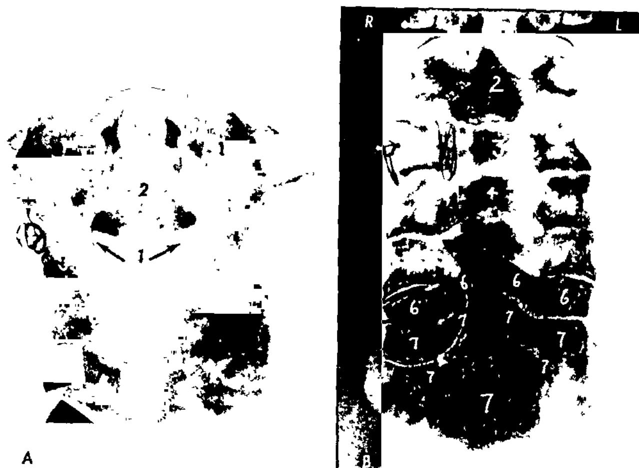


FIG. 2. Additional studies of the amputated neck of Cadaver A.

(A) The equivalent of an occipitosubmental view of the upper cervical spine, with magnified technic. *The entire ring of C-1 is visualized from above. The transverse* processes of C 1, 2 and 3 are seen clear of the other vertebral structures. The wire on the right transverse process of C-3 is anterior to the wire on the lamina. The lead squares in the lower apophyseal joints are seen almost completely *en face*. Thus, this view shows the entire cervical spine in an almost axial projection.

(B) Magnified anteroposterior view angled 30° caudad. Note that in this view both lead squares in the lower right apophyseal joints are seen on edge, and all the lower apophyseal joints are spread apart and clearly demonstrated. The body and the pedicles of C-7 are seen projected downward below the rest of the spine. Notice also that the right and the left laminae of the lower cervical vertebrae are visualized clearly and *symmetrically. This is a semiaxial view of the lower cervical spine. The top of the* roentgenogram is superoposterior; the bottom, infero-anterior.

to determine how the component parts of the cervical vertebrae are visualized. Wires were put on the laminae and transverse processes of selected vertebrae of each cadaver, and thin lead squares were inserted in two or three of the apophyseal joints of each cadaver.

Routine Views

Figure 1 shows anteroposterior, lateral and oblique projections of Cadaver A with the wires and the squares in position. On the anteroposterior view, as expected, the apophyseal joints are partly *en face*, and the transverse processes and laminae are not well seen because of superimposition. On the oblique views the transverse processes are thrown clear. On both the oblique views and the lateral views the laminae are fairly clear of the vertebral bodies but superimposed on other portions of the posterior rings. Rather surprisingly, the apophyseal

joints are not well demonstrated throughout. Only one of the marked joints is seen on edge on each of the oblique views, and only one on the lateral view.

Special Views

Modified Basilar View. On the equivalent of the occipitosubmental view, Figure 2A, the ring of C-1 is very well demonstrated, and the transverse processes of the upper cervical vertebrae are well demonstrated down to the wired transverse process of C-3. This appears to be a good axial view of the apophyseal joint area of the entire cervical spine, as the lead squares in the fifth and the sixth articulations are seen *en face.* The laminae of all the vertebrae but C-1 are poorly visualized because of superimposition. The transverse processes of C 1, 2 and 3 are well seen.

Clinically, this modified view is taken with slightly more tube angulation caudad than routine occipitosubmental views of the skull, focused and coned down sharply over the atlas. The view is somewhere between the basilar view of the skull and the exaggerated Waters view recommended by Jackson[8] for visualization of C-1. If the patient is unable to lie prone, the view may be taken supine as a modified submento-occipital view of the skull.

In our own experience this is the best view for visualization of the upper cervical vertebrae.

Thirty Degree Anteroposterior View. In only one view were all the apophyseal joints of the lower cervical spine seen completely unfolded, bilaterally and symmetrically—an anteroposterior view angled 30° caudad, as seen in Figure 2B This is a semiaxial view and also demonstrates the rings of the lower cervical vertebrae, particularly the laminae, quite adequately and symmetrically.

Clinically, this projection is taken with the patient lying supine, with the neck in hyperextension and the head held back by a band of muslin looped under the chin. A small cone is centered to C 6 or 7 and adjusted to project as little as possible of the chit. over the vertebrae, with the tube angled to as close to 30° caudad as possible.

In our own experience this is the best view for visualization of the smaller posterior elements of the lower cervical vertebrae.

Technic

We take both these latter special views stereoscopically, preferably with a short focal spot-object distance, utilizing an 0.3 mm. focal spot and magnification technic.[1] The differential magnification gained allows for much better separation of the cervical spine structures from each other and from overlying shadows. With the anteroposterior view angled caudad, the short focal spot-object distance grossly overmagnifies the vertebral bodies, so that, with the angulation, a virtual hemisection is accomplished for better visualization of the posterior elements. In the basilar view, C-1 is of necessity well removed from the table top, and the fine focal spot makes for a tremendous increase in clarity of detail with or without magnification.

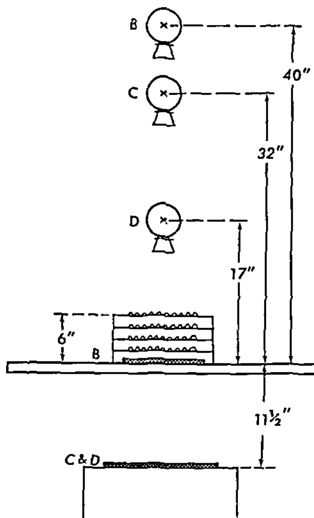
For the short-distance differential magnification technic, a very small flare cone is used—2¼-inch aperture at base, 3 inches at end, 9 inches long. A relatively high kv technic is used—90 to 100 kv—and 2¼ mm. of AL. filtration is added. These factors serve to reduce the amount of radiation to the patient and reduce the amount of scatter on the film. Measurements using this technic at Michael Reese Hospital[5] indicate that the dosage to the patient is at most about 0.6 r entrance dose and 0.03 r exit dose. More recently we have been using a more sensitive film available now, so that our exposures have been halved.

Figure 3 shows roentgenograms of a wire-screen phantom illustrating the effect of the differential magnification technic in separating the layers of the phantom for better visualization of the slits in the screen—



FIG. 3. Roentgenograms of wire-screen phantom to illustrate effect and value of differential magnification technic.

(A) Roentgenogram of 4 strips of wire screening, numbered and with cuts at various places; routine technic 40 inches focal spot-table top distance.



(B) Roentgenogram of assembled phantom composed of the wire strips seen in A. The strips are mounted over each other between empty film boxes so that Levels 1, 2, 3 and 4 are approximately 6, 4½, 3 and 1½ inches, respectively, above the table top. The film was on the table top, and a focal spot-table top distance of 40 inches was used.

(C) Roentgenogram of same phantom unchanged from position of B but utilizing a focal spot-table distance of 32 inches and with the film placed 11½ inches below the table top.

(D) Roentgenogram of same phantom now using focal spot-table top distance of 17 inches and with the film 11½ inches below table top.

(E) Diagram showing positions of phantom, x-ray tube and films.

In C and D the films were subjected to an over-all magnification because the film was placed below the table top, but the photographer has reproduced them all to approximately the same size for an adequate comparison of the differential magnification. It is to be noted that while the over-all magnification will depend in part on the distance of the film below the table top, the differential magnification depends only on the focal spot object distance, or as expressed above by the focal spot-table top distance.

(*Continued on facing page*)



FIG. 4. Magnified anteroposterior view angled 30° caudad of Cadaver A, as in Figure 2B but with metallic markers removed. In both Figures 4 and 2B there is noted pronounced lateral wedging of the right lateral mass of C-6. This is not seen in any of the other views because in each case the area is either overlapped or foreshortened. This lateral compression of the right interarticular isthmus of C-6 is due to a healing fracture. Fracture probably occurred 4 months prior to death when the patient fell out of bed. (See microscopic sections in Fig. 6.) Compare with similar findings seen clinically in Figure 7.

Note also the tilting upward of the superior facet of C-7 on the right and the rarefaction below. This corresponds to the defect seen in 1B. On hyperextension of the neck of this cadaver, the delicate cancellous bone in the right interarticular isthmus of C-7 crumbled, and on hyperflexion the superior facet was pulled up and away leaving a hole. Compare with the very similar findings in roentgenogram of accident patient in Figure 9A. (There is also a defect in the interarticular isthmus of C-4 on the right, produced experimentally with a chisel and not accompanied by elevation of the superior facet.)

simulating small localized fractures. While Figure 3C and D are reproductions of magnified films, the photographer has reproduced them to the same size as the unmagnified views to eliminate the factor of over-all magnification in comparing the roentgenograms. The two technics are complementary and not mutually exclusive. With the magnification we usually employ somewhat different criteria—looking for interruptions in small groups of trabeculae rather than over-all lines and changes in density.

FRACTURES

Three types of fractures of the smaller elements of the cervical vertebrae were produced experimentally on the cadavers, and

FIG. 3. (*Continued from facing page*)

In B, made with routine technic, Level 1 is [illegible] nore that Level 4. In C, the original film showed [illegible] with respect to routine film of B, but the relative [illegible] per cent more than Level 4, and as seen in the reproduction no advantage is gained. With the technic employed, there is a relative magnification of Level 1 of about 41 per cent more than Level 4, and the differences of the levels of the phantom are obvious.

It is readily apparent that in D the cuts in the various levels of the wire screen are seen much better than with the other technics. On the original film it is possible to identify interrupted wire strands in every one of the cuts and, from the differences in size, to identify the level of the cut. In clinical practice with this technic, one uses somewhat different roentgenographic criteria insofar as one searches for groups of interrupted trabeculations as well as for over-all breaks in contour of bone and linear changes in density. It is to be emphasized that the technic described is complementary to routine technic and not necessarily superior, except in selected regions or cases.

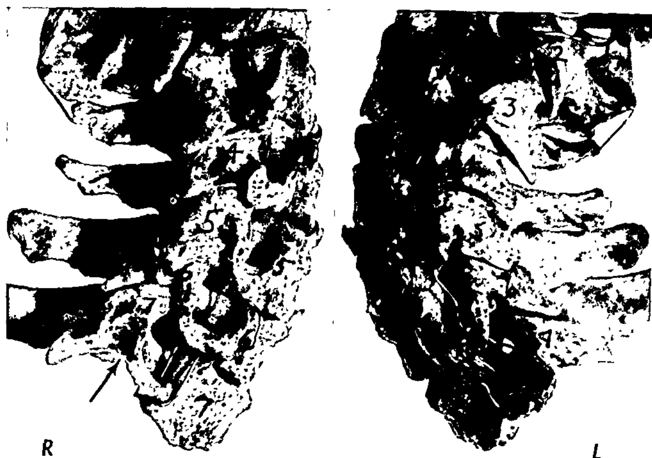


FIG. 5. Photographs of mounted vertebrae of Cadaver A. (*Left*) right side. (*Right*) Left side.

The arrow points to the defect in the intervertebral isthmus of C-7 induced by the hyperextension and hyperflexion trauma to the patient. It points also to the deformed right lateral mass of C-6, associated with a healing fracture of the interarticular isthmus Fracture probably sustained 4 months before death. In comparison with the normal left side, the lateral compression is well demonstrated. Also well seen is the anterior displacement of the superior facet, as compared with the inferior facet, indicating the result of a shearing force

Also to be noted is the fact that the lateral masses of C-5 are actually of equal size, even though their projections are unequal on the anteroposterior views angled caudad. The defect in the right lateral mass of C-4 was done with a chisel.

apparently the roentgenographic evidence of these fractures was duplicated in patients.

Fractures of the Interarticular Isthmus

The most common fractures produced in four of the six cadavers were through the interarticular cancellous bone of the lower cervical vertebrae. In two cases there was extension into the lamina.

On close examination of the serial roentgenograms of Cadaver A, it appeared that there was a minimal depression of the superior joint surface of C-7 on the right following the hyperextension phase of the experiment, and then a slight lifting up of the superior facet of C-7 on the right after the hyperflexion phase, with production of a rarefied area below. This is well seen in Figure 4. The defect below the superior facet is well seen in Figure 1B. It is to be noted that while these illustrations were made after amputation of the neck, the deep tissues about the fracture site are intact.

Our concept of the production of this type of fracture is as follows: With the neck in unilateral forced hyperextension, the

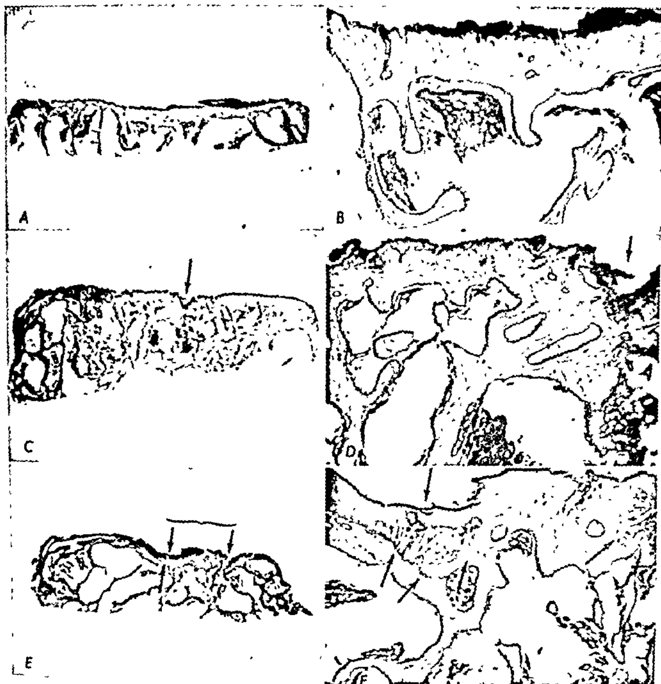


FIG. 6. Microscopic sections of the lateral masses of C-6 of Cadaver A.

(A & B) 12X and 50X magnifications of a section through the superior facet of C-6 on the normal left side. Note the regular pattern of the delicate trabecular structure.

(C & D) 12X and 50X magnifications of a section through the superior facet of C-6 on the abnormal right side. Note the grossly distorted, coarsened trabecular structure as compared with the normal side. Also seen is a defect in the joint surface.

(E & F) 12X and 50X magnifications of a section through the interarticular isthmus of C-6 on the right in area of the fracture. Note the grossly irregular, distorted trabecular structure. Fibro-osteoid tissue and cement lines are indicated by arrows. These findings are indicative of a healing fracture Fracture probably occurred when the patient fell out of bed 4 months prior to death

homolateral articulations are weight-bearing. The fragile cancellous bone between the facets is the weakest supporting structure and can be crushed at this stage of the whiplash. Then, on the reverse hyperflexion phase, the ligamentous traction on the superior facet may pull apart the fragments of the bone with further splitting Dependent

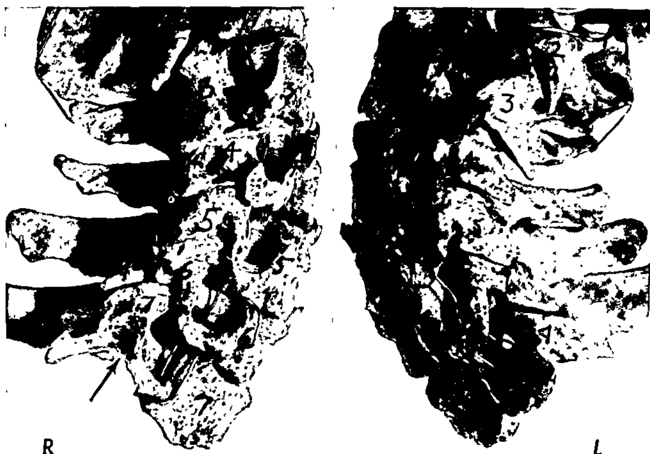


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Also to be noted is the fact that the lateral masses of C-5 are actually of equal size, even though their projections are unequal on the anteroposterior views angled caudad. The defect in the right lateral mass of C-4 was done with a chisel.

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On close examination of the serial roentgenograms of Cadaver A, it appeared that there was a minimal depression of the superior joint surface of C-7 on the right following the hyperextension phase of the experiment, and then a slight lifting up of the superior facet of C-7 on the right after the hyperflexion phase, with production of a rarefied area below. This is well seen in Figure 4. The defect below the superior facet is well seen in Figure 1B. It is to be noted that while these illustrations were made after amputation of the neck, the deep tissues about the fracture site are intact.

Our concept of the production of this type of fracture is as follows: With the neck in unilateral forced hyperextension, the



FIG. 8 Roentgenograms of M P., male, aged 56, who sustained whiplash injury in rear-end collision on July 23, 1956

(A) Magnified anteroposterior view angled 30° caudad, July 24, 1956. Note the displacement of the entire superior facet of C-6 on the left laterally.

(B) Oblique view in flexion, July 24, 1956. Note displacement of superior facet of C-6 on left anteriorly Compare with anterior displacement of superior facet of C-6 on right of Cadaver A.

(C) Magnified anteroposterior view angled 30° caudad, October 8, 1956. Note increased evidence of separation of superior facet since examination 3 months before, with some settling of the left lateral mass of C-6.

(D) Magnified anteroposterior view angled 30° caudad, December 6, 1956. Note fragmentation of superior facet of C-6 on left, with evidence of further settling of left lateral mass, 5 months after injury.

Diagnosis. Interarticular isthmus fracture of C-6 on left, with displacement of superior facet anteriorly and laterally.



FIG. 7. Roentgenograms of J. G., female, aged 30, hit by heavy metal lamp shade on November 12, 1955. The patient had persistent pain and tenderness in the right lower neck with radiation to the back of the right shoulder, subsiding gradually over 5 months.

(A) Nonmagnified anteroposterior view angled 20° caudad, November 18, 1955. Right and left lateral masses of C-6 measure 9 mm. and 13 mm. in height, respectively, a ratio of roughly 2:3.

(B) Nonmagnified anteroposterior view angled 20° caudad, January 16, 1956. Right and left lateral masses of C-6 measure 6 mm. and 12 mm. in height, respectively, a ratio of 1:2.

(C) Magnified anteroposterior view angled 30° caudad, January 16, 1956. Right and left lateral masses of C-6 measure 9 mm. and 18 mm., respectively, a ratio of 1:2, as in B. From front to back the lateral masses are at the same level; therefore, as should be expected, the ratio of their heights is independent of the degree of angulation or magnification

Diagnosis. Fracture of the right interarticular isthmus of C-6 with progressive compression (Compare with C-6 of Cadaver A, Fig. 4.)

on subsequent weight-bearing and stress and strain, the fragments may remain separated or compress

Cadaver A also supplied us with what we have reason to believe is an excellent example of a fracture of this type that occurred during life. Referring again to Figure 4, we note the marked lateral compression of the right lateral mass of C-6, not demonstrated on any other projection. The apparent unequal size of the lateral masses of C-5 in this view is due to projection, caused by tilting of C-5 to compensate for the compression of C-6.

Apparently, the deformity of C-6 has been caused by a fracture through the right interarticular isthmus, which probably occurred when this patient fell out of bed 4 months before death. Figure 5 comprises photographs of the specimen, showing the lesions of both C 6 and 7. It is to be noted that the interarticular isthmus of C-6 was subjected not only to a compression force laterally but also to a shearing force so that the superior facet is displaced anteriorly with respect to the inferior facet. Figure 6 shows microscopic sections of C-6 showing a healing fracture through the interarticular isthmus on the right.

Fifteen additional cadavers have been roentgenographed and subsequently dissected in a search for incidental premortem fractures In four additional cases of this group, evidence of fracture of the interarticular isthmus area was noted on the roentgenograms and confirmed by anatomic ex-



FIG. 10. Cadaver B.

(A) Magnified anteroposterior view angled 30° caudad. The arrow points to a defect in the interarticular isthmus of C-5 on the left. This was produced experimentally by forced hyperextension and flexion, as was the defect of C-7 in Cadaver A. In addition, in Cadaver B there was an extension of the defect into a longitudinal split of the left lamina of C-5. Compare with similar findings in Figure 11B.

(B) Photograph of mounted cervical spine specimen. Arrows point to the defect in the interarticular isthmus of C-5 on the left and the horizontal crack in the lamina. Compare with the very similar lesion of C-7 on the right, seen in the photograph of the specimen of Cadaver A, induced in the same way, but without the extension of the fracture into the lamina.

too, the fracture area was subjected to a shearing force.

The roentgenograms in Figure 9 demonstrate a clinical example of an interarticular isthmus fracture with separation of the fragments, as produced experimentally in the lateral mass of C-7 of Cadaver A. The elevation of the superior facet of C-7 in this patient's anteroposterior view, angled 30° caudad, as well as the subarticular defect in the oblique views, is strikingly similar to the corresponding views of the cadaver.

In Cadaver B a somewhat more extensive interarticular isthmus fracture was produced in C-5 on the left, with extension of a horizontal split into the lamina The defect is seen in the anteroposterior view angled caudad, as seen in Figure 10A, but the crack in the lamina was not demonstrated in any of the roentgenograms. The complete fracture is seen in the photographs of the specimen in Figure 10B.

Figure 11B shows in the anteroposterior view, angled caudad, an extremely similar fracture of the interarticular isthmus of C-5 on the left of a patient. It is to be noted that the fracture was not demonstrated in the straight anteroposterior view shown in Figure 11A or any of the standard views.

Figure 12 shows the marked deformities and rearrangements of the vertebrae consequent to the absence of the pedicle of C-6. Follow-up studies showed hypertrophic changes about the fifth interspace at the level of weakness.

Transverse Process Fractures of C-1 and/or C-2

The next most common type of fracture, both experimentally and clinically, was one

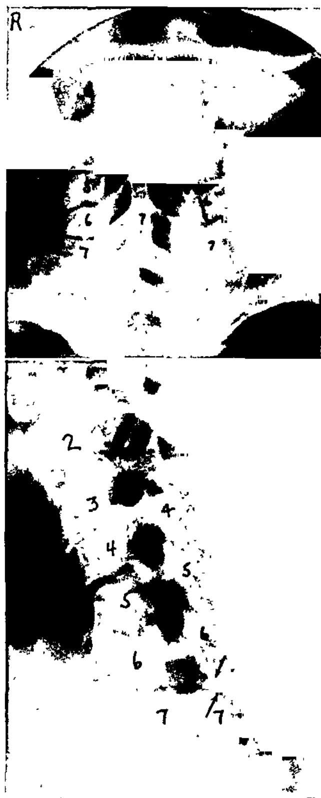


Fig. 9. Roentgenograms of R. T., male, aged 26, who sustained whiplash injury *in side-to-end collision on December 19,* 1955.

(A, *top*) Magnified anteroposterior view angled 30° caudad, January 4, 1956. Note the marked upward tilting of the superior joint surface of C-7 on the left, with pronounced underlying rarefaction. On the roentgenograms there were also noted tiny breaks in the cortex. Compare with the similar findings of C-7 of Cadaver A in Figures 2B and 4.

(B, *bottom*) Magnified oblique view in flexion. Note the defect in the interarticular isthmus of C-7. The cortex also is broken. Compare with very similar findings experimentally produced in Cadaver A, Figure 1B.

Diagnosis. Interarticular isthmus fracture of C-7 on left with pulling apart of *fragments.*

Follow-up roentgenograms of November 11, 1957, showed healing of the fine fracture lines and cystic changes in the lateral mass.

amination. Two were at the level of C-4 and one at C-6. Interestingly enough, all showed lateral compression and anterior displacement of the superior facet involved. Therefore, it would appear that the shearing force postulated above to explain the deformity of C-6 in Fig. 5 may well be characteristic of this type of injury. There was not a significant correlation of traumatic history with the cadavers evidencing old fractures, nor was there a significant correlation of symptoms in the premortem charts. It was our impression that arthritis was focalized about the site of injury.

Figure 7 shows serial anteroposterior roentgenograms, angled 30° caudad, of patient *demonstrating progressive* post-traumatic compression of the right lateral mass of C-6. Apparently, this patient suffered an interarticular isthmus fracture with end-result quite similar to premortem C-6 fracture of Cadaver A.

In Figure 8 are shown roentgenograms of another clinical example of an interarticular isthmus fracture, without as much collapse of the lateral mass. This example is especially interesting because it demonstrates anterior displacement of the superior facet, as seen in our studies of the premortem fracture of C-6 of Cadaver A. *Apparently here,*

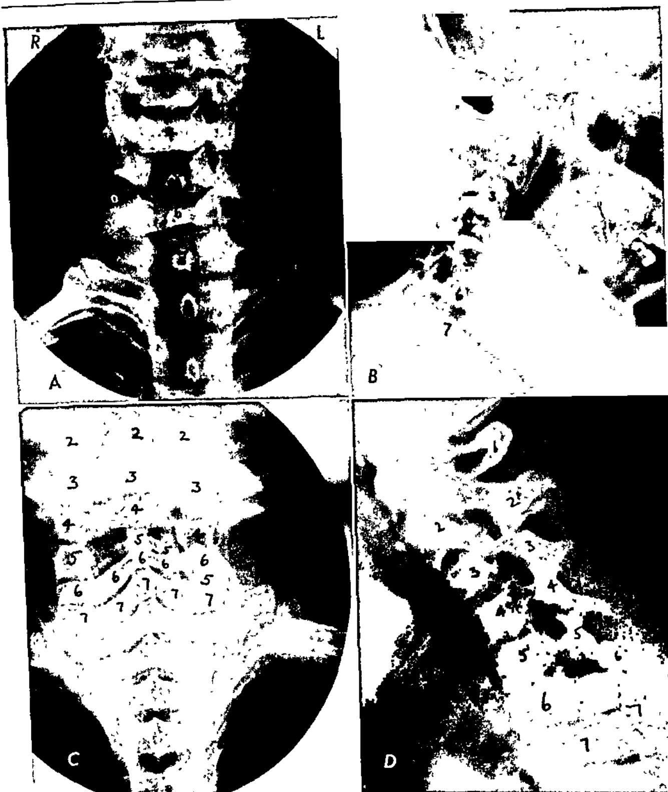


FIG 12 (*Continued from facing page*)
of C-5, indicating superior and posterior displacement. The lateral mass of C-6 is rotated and is superimposed on the lateral masses of C 4 and 5.

(D) Right posterior oblique view in flexion, January 31, 1956. Note that the left articular process of C-6 is displaced posteriorly and apparently unattached On stereoscopic viewing the pedicle of C-6 appears to be absent and the transverse process displaced inferiorly.

Diagnosis. Absence of the pedicle of C-6 on the left (not associated with this collision) with separation of the articular process and rotation and tilting of C 3, 4 and 5.



FIG. 11. Roentgenograms of A. T., female, aged 38, a passenger in a rear-end automobile collision on November 13, 1954.

(A, *left*) Magnified anteroposterior view, November 19, 1954. No fracture was noted in this view or other routine projections. Some hypertrophic change is seen in the articulation between C 4 and 5 on the left.

(B, *right*) Magnified anteroposterior view angled 30° caudad, March 9, 1955. On stereoscopic viewing of this projection there is apparently an ununited fragment of bone separated off the superior surface of the left lateral mass of C-5.

Diagnosis. Interarticular isthmus fracture of C-5 with separation of a portion of the superior facet.

involving the transverse process of C-1 and/or C-2. Some of these occur through the transverse foramen of the transverse process and are probably avulsion fractures. Others occur more medially on C-1, extending through the superior articulation, and are probably the result of the direct force of the whiplash transmitted down through the occipital condyle. The head is the weighted end of the whip, and it is to be expected that a considerable amount of force is transmitted in this fashion.

FIG 12. (*See facing page.*)

Roentgenograms of M. T., female, aged 31, injured in rear-end collision on January 28, 1956. Anteroposterior and oblique views are shown. Other views are not helpful.

(A) Magnified anteroposterior view. Note the abnormal appearance of the left lower spine with what appears to be an overlapping osseous structure.

(B) Lateral view in flexion Note lack of flexion in lower cervical segment associated with muscle spasm

(C) Magnified anteroposterior view angled 30° caudad, January 31, 1956 Note the marked tilting downward of C 3, 4 and 5 on the left, indicating both inferior tilting and anterior rotation The left lamina of C-6 is directed upward, crossing over the lamina

(*Continued on facing page*)



FIG. 15. Magnified submento-occipital view of M. P., female, aged 29, passenger in a head-on automobile collision on September 9, 1955. The patient had immediate headache, was dazed and had blurring of vision. She had a cord bladder and bowel which gradually improved but did not completely disappear over a period of 9 months.

There is a gross difference between the transverse processes of C-1 with a defect at the base of the right transverse process posteriorly indicated by the arrow. On stereoscopic viewing a fracture apparently extends completely through the base of the right transverse process, and the entire process is angulated anteriorly and rotated inferiorly. The posterior ramus of the right transverse foramen is seen *en face*, and the anterior ramus is completely separated. On the open mouth view there was a slight offset of C-1 laterally to the right on C-2. Callus is seen on subsequent examinations A vertebral angiogram may be done later to see the effect of this fracture on the vertebral artery as it passes through the transverse foramen.

Fractures of the Joint of Luschka

The last of the fracture types occurs through the joint of Luschka (the neurocentral lip articulation), breaking off the unciform process of the vertebra below and disrupting the cortex of the joint in the vertebra above. These joints contribute to the lateral motion and stability of the neck, and the fractures could occur as a result of the forced lateral flexion. This fracture is a very difficult one to demonstrate but, as noted by Borealis and Gershon-Cohen,[3] the joint is quite important by reason of its proximity to nerve roots.

Both of these latter fractures were produced on Cadaver C. Figure 13 shows the roentgenographic demonstration of both fractures, with photographs of the specimen.

The fracture of the right transverse process of C-1 is readily demonstrated in the roentgenogram. The fracture through the elements of Luschka between C 2 and 3 on the left is harder to see and, in fact, was not noticed until after the fracture was discovered in the specimen. On close inspection the absence of the unciform process of C-3 on the left and the break in the cortex of C-2 are demonstrable.

Figure 14 shows a fracture of the left transverse process of C-1 in much the same place as the one of the cadaver. This fracture was not visible in the open-mouth view or other views This is usually the case because the lateral fragment is commonly displaced medially or anteriorly and the displacement is hidden on the anteroposterior projection.

Figure 15 shows a fracture of the right transverse process of C-1 which is more medial in position and extends into the superior facet. This fracture also was not visible in the open-mouth view, but there was considerable offset of C-1 laterally to the right on C-2. In agreement with Jacobson and Adler[9] we have found this to be an excellent indirect sign indicating the possibility of fracture. In our experience, a consistent unilateral offset is usually associated with a



FIG. 13. Cadaver C.

(A) Anteroposterior view of amputated stump of neck with deep tissues intact. The fracture of the right transverse process of C-1 is of the avulsion type, produced experimentally by forced hyperextension and flexion to the left. Compare with similar fracture found clinically in Figure 15. Note also the absence of the left unciform process of C-3 and the small cortical defect above in C-2. These findings are those of an experimentally produced fracture with fragmentation of both elements of the joint of Luschka between C 2 and 3 on the left. Compare with similar findings of patient I. B., Figure 16.

(B) Photographs of mounted cervical spine specimen. The lateral fragment of the transverse process of C-1 on the right is now absent. The areas of fragmentation of the joint of Luschka between C 2 and 3 on the left are indicated by arrows marked on the specimen and are to be contrasted with the normal configuration on the right side.



FIG 14 Occipitosubmental views of M. G., female, aged 46, in automobile collision 5 months previously. The patient had persistent left occipital headaches, pain on rotation of the head to the right and intermittent shooting pains localized to the left mastoid area Multiple routine examinations of the cervical spine, including open mouth views. were negative

(A) Nonmagnified basilar view of skull shows some asymmetry of the transverse processes of C-1, but it is difficult to identify a fracture.

(B) Magnified basilar view, slightly oblique, shows fracture through the left transverse process of C-1 with medial displacement of the lateral fragment and encroachment on the transverse foramen

fracture of C-1 or a rotation of C-1 with respect to C-2 and the occiput. This patient also had a fracture through the ring of C-1.

Figure 16 demonstrates a clinical example of a fracture of the joint of Luschka.

DISCUSSION

In general, fractures of the types demonstrated occurred both experimentally and clinically at the levels of C 1 and 2 and/or in the lower cervical vertebrae. The clinical examples used for illustration were of relatively young patients with little or no osteoarthritis and with lesions closely approximating those of the cadavers.

The localization of fractures to C 1 and 2 is probably due to the effect of the pronounced localized force of the weighted end of the whip—the head. The localization to the lower cervical spine is probably because of the change in flexibility present at this level by reason of the transition from the relatively fixed thoracic spine to the relatively free cervical spine.

Exceptions to this localization occur commonly in the presence of fixation of all or part of the cervical spine because of arthritis or congenital lack of segmentation. Fractures then occur at a point of change in flexibility above or below the area of partial or complete fixation. The fracture of the joint of Luschka in the upper cervical spine of Cadaver C probably represents an example of this phenomenon because the lower cervical spine was markedly fixed by extensive osteoarthritis.

It is our clinical impression that the relatively inflexible neck is more susceptible to whiplash fracture than the normal one. Usually it is more difficult to demonstrate the fractures in presence of arthritis or anomaly.

In our experience thus far we have found that characteristically, the lateral masses of the lower cervical vertebrae are smooth and symmetric in children but that the incidence of asymmetry and deformity increases steadily with increasing age. In the C 1 to 2 area too, deformities are relatively common in the aged.

Most of the asymmetries are quite minimal, and possibly are akin to the asymmetric vertebrae found elsewhere in the spine, associated with long-standing scoliosis and postural defects. However, in many other cases quite marked deformities are found.

We have come to the conclusion that minor fractures of the neck must be quite common and rather frequently are found as incidental findings on roentgenograms. The high incidence of fractures in our cadavers tends to confirm this point. Moreover, from close questioning of patients, these fractures apparently have a wide range of severity of symptoms, and the symptoms may be quite nonspecific.

From a practical standpoint, in attempting to attribute a fracture to a recent injury, we tend to ignore minor asymmetries and, except in the most obvious cases, insist on comparison roentgenograms in about 2 months for confirmation. Demonstrable changes are slight and slow to appear, as in other flat bones. Additional rechecks in 6 months, or even longer, may be necessary for complete certainty, especially in the aged.

SUMMARY

Three types of cervical fracture were produced experimentally by unilateral forced hyperextension and hyperflexion of the necks of cadavers and found to occur clinically associated with relatively minor predominantly unilateral whiplash injury: (1) Fracture of the interarticular isthmus and lamina of one or more of the lower cervical vertebrae; (2) fracture of the lateral process of C-1 and/or C-2; and (3) fracture of the elements of a joint of Luschka.

Usually, these fractures are not visualized in routine views of the cervical spine. In our experience, two additional stereoscopic views are necessary, preferably *with direct* magnification technic: (1) a modified basilar view of the skull, *centered over C-1, for* adequate visualization of C 1 and 2; and (2) an anteroposterior view angled about 30° caudad for adequate visualization of the posterior elements of the lower cervical vertebrae.

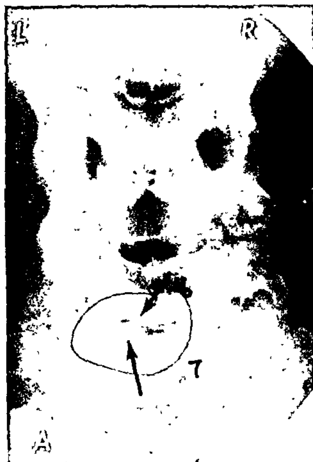


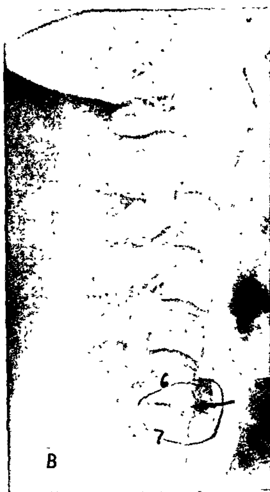
FIG. 16. Roentgenograms of I. B , male, aged 24, injured July, 1955, in motorcycle-automobile accident. The patient had persistent pain in the lower neck on the left with palpable and audible crepitus.

(A) Magnified posteroanterior view angled 15° cephalad, December 16, 1955. The absence of the unciform process of C-7 on the left and the defect in C-6 are well seen. Compare with Figure 14A showing fracture of joint of Luschka of Cadaver C.

(B) Magnified lateral view, December 16, 1955. A sliver of bone off the inferior cortex of C-6 is demonstrated. There is narrowing of the sixth interspace.

(C) Tomogram at 8½-cm. level The defects of C 6 and 7 are well demonstrated, together with secondary lipping.

Diagnosis. Fracture of both elements of the left joint of Luschka between C 6 and 7 with thinning of the sixth intervertebral disk.





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Moderatemente Sever Vulneres "a Colpo de Flagello" in le Spina Cervical e lor Diagnose Roentgenologic

Summario in Interlingua

Tres typos de fractura cervical esseva producite experimentalmente per fortiate hyperextension e hyperflexion unilateral del collos de cadaveres. Illos esseva (1) fractura del isthmo interarticular e del lamina de un o plures del vertebras infero-cervical, (2) fractura del processo lateral del vertebra C-1 e/o C-2, e (3) fractura del elementos de un articulation de Luschka. Esseva establite que iste typos de fractura occurre clinicamente in association con *minor e predominantemente unilateral* vulneres "a colpo de flagello." Fracturas del isthmo interarticular es le plus commun, sequite in frequentia per le altere typos in le ordine de lor enumeration in supra.

Usualmente iste fracturas non es visualisabile in routinari roentgenogrammas del spina cervical—tanto in experimentos con cadaveres como etiam in le caso de patientes. A causa de isto, duo expositiones additional esseva testate in specimens anatomic e applicate in situationes clinic. Illos esseva (1) un modificate vista basilar del cranio, centrate super C-1 in le interesse de un visualisation adequate de C-1 e de C-2 e (2) un vista antero-posterior, con angulation de 30 grados in direction caudal in le interesse de un visualisation adequate del elementos posterior del vertebras infero-cervical. Il es nostre opinion que le melior visualisation es obtenite quando ambe iste expositiones special es effectuate stereoscopicamente con un technica de magnification differential. Iste technica utilisa le tubo a 0.3 mm. de area focal e un curte distantia inter area focal e objecto.

In nostre sectiones de specimens de spina cervical e in nostre studios clinic nos ha trovate que indicios de curate minor fracturas es satis commun. Illos interessa con frequentia particular le parte interarticular del vertebras infero-cervical. Per consequente, in le evaluation clinic de recente vulnerationes il es frequentemente desirabile o mesmo necessari obtener studios de consecution pro confirmar e evalutar de maniera adequate le diagnose roentgenologic.

19

The Repair of Articular Surfaces Following Arthroplasty of the Hip*

MARSHALL R. URIST, M.D.†

Biopsy specimens of unsuccessful arthroplasties of the hip joint have been readily available in recent years. Of more than 100 arthroplasties observed by the author between 1946 and 1956, at least 20 per cent were treated by revision, arthrodesis or replacement by a prosthesis Shavings and scrapings of tissue from the surface of the head were obtained from hips with all different kinds of joint disease; in a few instances, the surgical operation provided a large part of the head, the whole head, and even the head and the neck. In this communication, the tissue removed from 15 reoperations and one necropsy will be described with the aid of newer laboratory methods for study of connective tissue. An attempt will be made to correlate the capacity of the femoral head for repair with the original disorder of the hip joint and to describe the differences between cartilage in normal joints and cartilage formed following arthroplasty. The author will speculate on the clinical significance of his observations wherever he can corroborate, or find support in, material described in the literature on arthroplasty without[14], as well as with,[1,2,9,11,22,23] the Vitallium cup.

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† Los Angeles 24, Calif., UCLA Medical School.

MATERIALS AND METHODS

Fifteen arthroplasties, 8 with Vitallium mold of the Smith-Petersen design and 7 with the author's Vitallium hip socket were the source of tissues for this study. Eight joints showed the early stages of repair from 6 to 12 months of healing. Two joints showed the intermediate stages from 12 to 18 months of healing. Five joints showed all stages of development of the articular surfaces from 18 months to 5 years after the operation. The cartilaginous femoral heads in a 26-week-old fetus were examined to compare embryonic cartilage with regenerating cartilage. The heads of the femur from 3 autopsies on individuals in the sixth and the seventh decades of life were examined to compare normal adult cartilage with hyalinelike cartilage from arthroplasties (Tables 1 & 2).

One autopsy specimen was obtained from a patient with a successful arthroplasty who died of a brain tumor 3 years after the operation. Dr. Otto E. Aufranc and Dr. William Jones contributed sections of an autopsy specimen of a successful arthroplasty 5 years following an operation performed by Smith-Petersen. A serial section, but not the same section, of this specimen was described by Dr. Granville Bennett.[23]

The tissues were treated by fixation in neutral formalin or Zenkerformol, and stained by 6 different methods: (1) hema-

TABLE 1. ANALYSES OF UNSUCCESSFUL ARTHROPLASTIES OF THE HIP JOINT

Case No.	Age	Preoperative Diagnosis	Vitallium Implant	Months Healing	Cause of Reoperation	Final Treatment
1	34	Rheumatoid arthritis	Cup	6	Ankylosis	Revision
2	35	Rheumatoid arthritis	Socket	6	Ankylosis	Revision
3	35	Osteochondromatosis	Socket	8	Ankylosis	Revision
4	40	Old fracture-dislocation	Cup	11	Pain	Colonna operation with cup
5	32	Avascular necrosis, osteochondritis dissecans	Cup	11	Pain	Arthrodesis
6	68	Rheumatoid arthritis	Socket	11	Pain	Revision
7	37	Old Legg-Perthes disease	Socket	12	Ankylosis	Revision
8	39	Solid blast injury, avascular necrosis	Socket	12	Pain	Revision
9	35	Rheumatoid arthritis	Socket	14	Ankylosis	Revision
10	39	Old fracture-dislocation	Cup	18	Pain	Revision
11	38	Old fracture-dislocation	Cup	19	Pain	Arthrodesis
12	34	Avascular necrosis, osteochondritis dissecans	Socket	36	Pain	Moore prosthesis
13	49	Avascular necrosis, osteochondritis dissecans	Cup	29	Pain	Moore prothesis
14	32	Avascular necrosis, osteochondritis dissecans	Cup	48	Ankylosis & pain	Arthrodesis
15	50	Avascular necrosis, osteochondritis dissecans	Cup	60	Ankylosis & pain	Arthrodesis
A*	60	Old fracture of acetabulum*	Socket	36	Autopsy	None

* A = Autopsy

toxylin-eosin and Azure II for cellular structure; (2) toluidine blue or Azure II for metachromasia; (3) periodic acid and Schiff reagents for ground substance; (4) Mallory's azan for collagen; (5) phosphotungstic acid and hematoxylin for collagen; (6) Wilder's stain or Foot's method for reticulin.

Small samples of the joint in 6 cases were analyzed for hexosamine by the method of Boas and for hydroxyproline by the method of Neuman and Logan.

THE NATURE OF THE PREOPERATIVE PATHOLOGIC LESION AND THE VARIOUS CONDITIONS THAT LED TO REOPERATIONS

The 15 biopsies described in this report were obtained from hips with various disorders of the structure of the joint of known and unknown etiology. The classification of these disorders is of necessity arbitrary and and in most cases is based on clinical records and roentgenographic examinations covering a brief period of time Relatively few patients with arthroplasties for so-called malum coxae senilis have been available for reoperation and study up to this time. The author's patients in this category (1) had the best results, (2) were satisfied with the function that they had gained, (3) did not use their joints strenuously, or (4) presented other conditions such as cerebral arteriosclerosis, heart disease, etc., that discouraged multiple operations.

Fracture-Dislocations, Fracture of the Acetabulum and Solid Blast Injury

In 3 biopsied arthroplasties (Cases 4, 10, 11) the original disorder was clearly post-traumatic degenerative joint disease. In one additional biopsied hip (Case 8), the condi-

TABLE 2. CHEMICAL COMPOSITION OF NEW JOINT SURFACES

STRUCTURES AND SUBSTANCES	26-WK. FETAL FEMORAL HEAD	CONTROL ADULT FEMORAL HEAD	ARTHROPLASTIES: 6 MOS. (Cases 1 & 2)	ARTHROPLASTIES: 11 - 14 MOS. (Cases 6 & 9)	ARTHROPLASTIES: 48 - 60 MOS. (Cases 14 & 15)
Characteristic cells	Growing Chondrocytes	Flattened Encapsulated Chondrocytes	Fibrous Connective Tissue cells	Fibrocartilage cells	Hyaline-like Cartilage (paired chondrocytes)
* Fibrinoid	0	0	4+	2+	1+
Periodic acid Schiff reaction	4+	2+	4+	2+	2+
Metachromasia (toluidine blue or Azure)	2+	4+	1+	2+	4+
† Total sulfur	5.0	7.8	1.4	3.6 - 4.0	4.8
Collagen	2+	4+	1+	2+	4+
Fiber arcades	0	4+	0	0	1+
‡ Hydroxyproline	42.0	70.6 - 226.0	26 4 - 40.0	41 - 44	58.0 - 97.6
‡ Total collagen	318.0	581 - 1,715.0	200 - 302 0	310 - 333	440 - 739
‡ Total hexosamine	3.5	4.8	2.0	2.0	4.9 - 7.4
Paired chondrocytes	0	0	0	0	+
Articular cortex	0	4+	0	0	2+
New cartilage in subarticular cancellous bone	—	0	0	4+	1+
§ Estimate of mm of bone absorbed from surface of femoral head	—	—	2	3	3 - 5

* Estimate of the morphologic quantity: 1+ = trace; 2+ = appreciable; 3+ = definite amount; 4+ = large amount

† Milligrams per gram of dry weight of the tissue (Single numbers indicate the average of two nearly equal figures)

‡ Micrograms per milligram of dry weight of the tissue. (Double figures indicate the range)

§ Based on examination of roentgenograms.

tion for which the arthroplasty was done was so-called solid blast injury to the hips from an explosion under the deck of a ship. All these patients showed loss of joint space and increased radiopacity with a suggestion of flattening of the anterior portion of the femoral head. It was assumed that when these changes appeared between 6 and 18 months after a dislocation of the hip joint, there was avascular necrosis of bone.[21] Therefore, the circulation to the femoral head was probably not normal in these cases before the arthroplasty operation. There is also good probability, though not a certainty, that the arthroplasty performed on these joints damaged the blood supply to the

femoral head more than it already had been reduced by the accidental trauma. Disintegration of the entire femoral head occurred within 12 to 18 months after the arthroplasty in some of these hip joints. In such instances, flattening of the femoral head and the amount of actual fragmentation of bone structure were more extensive than in cases of accidental post-traumatic avascular necrosis. This suggested that surgical exarticulation of the joint during an arthroplasty could add injury to an already impaired circulatory system in the femoral head. One arthroplasty recovered at autopsy (Case 16) 3 years after the operation was done for degenerative joint disease secondary to a fracture of the acetabulum. In this case, the circulation to the femoral head was probably normal before the arthroplasty; after the operation, the head developed subchondral bone cysts and increased in density in some parts. One case provides too little evidence to conclude that the surgical procedure destroys blood supply to bone, but this one was highly suggestive in the light of other instances described below.

Nontraumatic Avascular Necrosis of the Femoral Head

The preoperative roentgenograms of five of the biopsied hip joints showed increased density of the bone, sequestration of cartilage and bone, and various degrees of loss of the spherical shape of the superior portion of the femoral head; but there was no history of injury, and the clinical diagnosis was either old osteochondritis dissecans or avascular necrosis, etiology undetermined (Cases 5, 12, 13, 14 & 15). The surgical procedure of the arthroplasty in these cases also seemed to have the same adverse effect on the circulation of the femoral head as in post-traumatic avascular necrosis and resulted in further loss of bone from the femoral head.

Degenerative Joint Disease

Two biopsies were obtained from joints (Cases 3 & 7) without any appreciable increase in the radiopacity of the femoral head, but with ankylosis due to loss of articular cartilage, enlargement and distortion of the femoral head, and intra-articular loose bodies. The clinical diagnoses in these cases was degenerative joint disease secondary to osteochondromatosis in one and healed Legg-Perthes disease in the other. These joints probably had developed some collateral circulation, and the surgical procedure of arthroplasty in these instances was not followed by disintegration of the femoral head.

Rheumatoid Arthritis

Four biopsies were obtained from patients (Cases 1, 2, 6 & 9) with proven rheumatoid disease. In two of these instances, the disease was classified as Marie-Strümpell ankylosing spondylitis. In all cases, the subchondral bone was atrophied; the radiopacity of the femoral head was diminished; there was no appreciable distortion of the shape of the femoral head. However, the thickness of the articular cartilage and the joint space was reduced, and the synovial membranes showed focal accumulations of acute and chronic inflammatory cells and fibrinoid. The circulation of blood through the femoral head was quite sufficient to produce good fibrocartilage under these conditions, but the disease was still active in these patients, and the soft parts would not move the new joint.

THE TWO FORMS OF REPAIR OF THE JOINT

The gross appearance of the joint exposed during reoperations, and the microscopic appearance of various amounts of tissue available in each case showed that there were two different pathways of repair following the first arthroplasty. The first is to be described in this chapter as *disintegration and fibrous repair* and the second as *fibrocartilaginous repair with formation of new articular cartilage.*

DISINTEGRATION AND FIBROUS REPAIR

Seven arthroplasties (Table 1, Cases 4, 5, 8, 10, 11, 12 & 13), all with clinical diagnoses of either post-traumatic or nontraumatic avascular necrosis of the femoral head, showed extensive resorption of bone and no appreciable regeneration of fibrocartilage. It is important to mention that in all instances in this category the clinical records revealed that joints were painful almost from the very beginning of the time the patients were allowed to move the joint. Judging from the first postoperative roentgenograms showing almost the full length of the neck remaining outside the cup, it was assumed that relatively little of the femoral head had been reamed away and that dead bone was present inside the cup. This assumption was substantiated further by serial roentgenograms showing gradual drifting of the greater trochanter toward the femoral head and progressive shortening of the length of the lower extremity. The findings at the time of the reoperations described below show that there can be no doubt that necrotic bone does not persist intact and is absorbed eventually inside the cup.

The Femoral Head. One year after the operation the head of the femur consisted of only an irregular knob of dense cancellous bone on the inferior side of the end of the femoral neck. The superior portion of the head was either absent or broken up into small fragments of dead bone enclosed in fibrinoid, scar tissue, and inflamed synovial membrane and scattered throughout the joint. Microscopically, the tissues consisted of loose and dense fibrous connective tissue containing macrophages, foreign-body giant cells, polymorphonuclear leukocytes, lymphocytes and other round cells.

The Femoral Neck. The entire femoral neck was removed for a Colonna reconstruction in the patient (Case 4), and the specimen showed increased density roentgenographically and microscopically due to endosteal appositional new bone formation. The process as seen 11 months after a cup arthroplasty was similar to that seen at some distance from the bone ends of all healing fractures. In 6 other cases, scrapings of tissue showed small patches of fibrous tissue and fibrocartilage around the circumference of the stump of the neck and covering viable areas of bone.

In patients who had made an effort to bear weight on the joint, a groove of eburnated bone was found wherever the rim of the cup impinged upon the neck. Some of these arthroplasties had a very good range of motion; in fact, too much motion, as generally there was abnormal excursion of the femoral head on the rim of the acetabulum and painful instability of the hip joint.

Synovial Membrane. The synovial membrane was thickened and reddened, and included a number of greatly swollen, hypertrophied synovial villi. The larger villi were nodular in shape, blue-black or purple in color, 1 cm. in size, and grew in clusters like grapes in the posterior and the inferior part of the joint. Microscopically, all parts of the joint inside and outside the cup or socket showed that this represented a nonspecific nodular synovitis. There were patches of old fibrin, hemosiderin, bits of necrotic bone and extensive round-cell infiltration inside the old and newly regenerated synovial membrane.

This form of synovitis was found in every one of the 7 arthroplasties in which persistent postoperative pain was the chief indication for reoperation and the cause of failure of the arthroplasty. Furthermore, this extensive form of nodular synovitis was not seen in reoperations on joints in which the head of the femur was not necrotic and did not disintegrate. Thus it would seem that nodular synovitis was an aftermath of necrosis of the femoral head.

Subchondral Bone Cysts. Five arthroplasties in this series showed subchondral bone cysts. These cysts contained granulation tissue, fibrous connective tissue, fibrocartilage, hyalinelike cartilage, mucin and some new bone, and they appeared beneath

the surface of the head of the femur at approximately the same time as fibrocartilage appeared on the surface of the femoral head. Cysts often are seen in osteoarthritic hips before surgical treatment and have been regarded as foci of "traumatic necrosis." Cysts have also been described in both autopsy specimens of successful arthroplasties[23] and biopsy specimens of unsuccessful arthroplasties,[8] in all kinds of hip disorders, and it is reasonable to assume that they can be associated with surgical injury as well as joint disease and are a deviation in the pathway of the process of repair of the femoral head. (See Fig. 8A, *top*.)

The Epiphyseal Line. Three specimens of the femoral head were large enough to include the epiphyseal line. The absence of the old epiphyseal line was a good indication that the bone structure in the interior of the femoral head had been resorbed and remodeled. When the epiphyseal line persisted, it was assumed that the bone tissue in that area was not necrotic or undergoing resorption or replacement.

Fibrocartilaginous Repair With Formation of New Articular Cartilage

Eight cases examined by biopsy (Table 1, Cases 1, 2, 3, 4, 6, 7, 9, 15 & A) and one case examined at autopsy showed some resorption of subchondral bone and some reduction in the size of the femoral head. However, disintegration of bone structure was minimal or did not appear to be imminent. The joint space was filled with a clear mucinous fluid less viscous than synovial fluid and much like bursal fluid.* Microscopically, these cases had in common the appearance of a proliferative process in the endosteum of the reamed surfaces on both sides of the joint. Judging from the preoperative and the postoperative roentgenograms, these cases showed that there was either no dead bone in the head or that a great deal of it had previously been reamed away correctly by the surgeon. The reparative process progressed through three stages that varied greatly in rapidity and yield of new tissue and overlapped more or less in time of appearance.

The Fibrous Stage (6 Months). Two arthroplasties were revised at approximately 6 months and one at 8 months after the operation (Cases 1, 2 & 3); the roentgenologic density of the head and the neck was relatively normal before and after the operation in these cases. The head of the femur on the operating table, at 6 months, showed a thick layer of ragged, reddish-gray connective tissue. The same kind of tissue formed an envelope for the cup or socket, measured 1 to 2 mm. in thickness, and consisted of an outer layer of amorphous material recognizable as fibrinoid and an inner layer of fibrous connective tissue. The fibrous layer consisted of chronic inflammatory tissue and young connective-tissue cells with a loose arrangement of ground substance, collagen and reticulin.* The two components fibri-

* Synovial Fluid. A body fluid with the composition of a dialysate of the blood plasma and an additional component mucin in concentrations of 0.1 Gm. of mucin nitrogen per 100 cc. of joint fluid.

Mucin. A highly viscous substance or lubricant found in synovial fluid composed of an easily dissociable complex or combination of hyaluronic acid and protein

Hyaluronate. A highly viscous mucopolysaccharide composed of hexuronic acid and a nonsulfated hexosamine (glucosamine) characteristically found in synovial fluid and bursal fluid.

* Ground Substance. A jellylike, interfibrillar, extracellular material composed of various mucopolysaccharides and other substances found in all connective tissue.

silver was the same in reticulin and collagen in the young connective tissue and in the new cartilage and bone found in healing arthroplasties.

Fibrinoid. A mixture of substances that appear as an acellular amorphous mass under the light

collagen, protein and unidentified material from necrotic cells. It has been described in the core of rheumatoid nodules in the lining of bursal cavities and the center of pseudarthroses. On the basis of its histochemical properties, fibrinoid appears, in part, to be a precipitate or coagulated form of the ground substance.



FIG. 1. Photograph of a Vitallium mold after it was removed from the hip joint during a revision operation after 18 months of healing. A plaque of fibrinoid 3 cm. in length, 2 cm. in width and 1 mm. in thickness was found in the location that is shown inside the mold. This was loosely attached and split away from the surface of the head when the joint was disarticulated. The dotted line indicates the line of section of the histologic preparations shown in Figure 2.

noid and fibrous tissue were nearly equal in amount around the margin of the head; inside the cup there was twice as much fibrinoid as fibrous tissue. In the underlying cancellous bone, there was an irregular zone of partially necrotic and partially normal bone measuring 1 to 2 mm. in thickness. The bone marrow in this area was fibrous, and there were also proliferation and differentiation of new bone from endosteum. Except for a few very small islands distributed haphazardly here and there in the deep layers of the viable subchondral bone tissue, fibrocartilage was not visible at this stage (Figs. 1-5).

Fibrocartilaginous Stage (1 Year). Four arthroplasties (Cases 4, 6, 7 & 9) with an intact femoral head were revised between

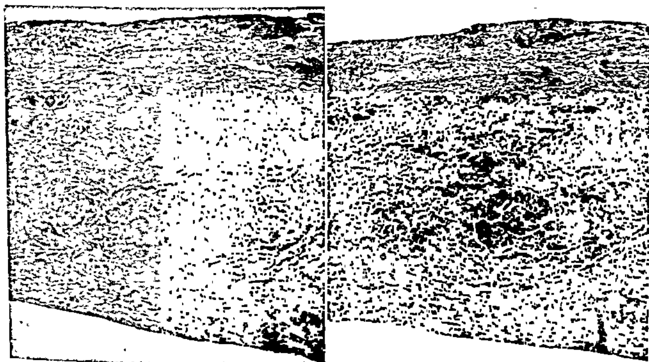


FIG. 2. (*Left*) Photomicrograph (×75) of plaque of fibrinoid shown in Figure 1. This material is acellular, and, like ground substance of connective tissue, it is amorphous and pink staining with periodic acid and Schiff reagents. (*Hotchkiss method*) (*Right*) Serial section of specimen shown in Figures 1 and 2, *left*, with phosphotungstic acid and hematoxylin showing an acellular collagenous component of fibrinoid. (×75)

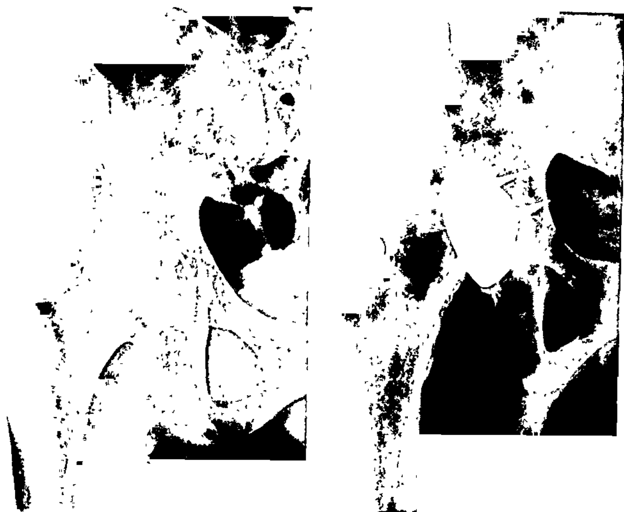


FIG. 3. (*Left*) Roentgenogram of hip and sacro-iliac joints of a 34-year-old man afflicted with *Marie-Strümpell ankylosing spondylitis. (Right) Roentgenogram of joint* shown at *left* 6 months after hip-socket arthroplasty. The length of the femoral neck is almost normal, indicating no loss of bone structure from absorption of the femoral head inside the socket. Ankylosis recurred in this case owing to periarticular ossification between the neck of the femur and the acetabulum.

11 and 14 months after the first operation. Grossly, the head of the femur was dome shaped with a convoluted surface rather than spherical and showed a dense fibrous connective tissue, including varying amounts of granulation tissue and chronic inflammatory tissue. In the average case, the bony portion of the femoral head was estimated to be ½ inch smaller in diameter than it was after the first arthroplasty. The volume of the cancellous bone tissue that was absorbed appeared to a large extent to have been replaced by the new soft tissue covering.

Microscopically, the covering of th oral head and the envelope of th socket was slightly thicker at 12 to 18 months than that observed at 6 months. The most important change was in the deep layer covering the head of the femur. Here the predominating cells were fibrocartilage cells, spindle shaped and with a small amount of basophilic matrix and a branching network *of intercellular argyrophilic fibers, recognizable* at reticulin. There were also small islands and cords of fibrocartilage growing between the bone trabeculae beneath the surface of the head. In the same areas there were even dep new bone aligned parallel to the the head and between the old t f cancellous bone.



FIG. 4. Roentgenogram of a specimen of the femoral head removed during a revision operation on the joint shown in Figure 3. Note the line of condensation of new bone to form a new articular cortex on the surface of the head.

This appeared to be the beginning of the formation of a new articular cortex. (Figs. 3-5)

Cartilaginoid Stage (2 to 5 Years). Two cup arthroplastics performed originally for healed "osteochondritis dissecans" (Cases 14 & 15) were reoperated upon to produce an arthrodesis between 48 and 60 months after the first operation. The head of the femur was not spherical but dome shaped and only as wide as the neck of the femur. The superior or weight-bearing portion of the dome was covered with a thin translucent grayish-white articular surface. After 2 or more years of healing, the bony dimension of the femoral head was estimated to be ¾ inch smaller in diameter than it was before the arthroplasty, and approximately ½ inch smaller than it was immediately after the operation. These estimates were made from preoperative and postoperative roentgenograms of the anteroposterior view of the hip joint with allowances made for magnification and by direct measurements made by trying on hipsockets of different sizes. In our few cases the repair of the joint following arthroplasty appeared to be a process of remodeling the femoral head from the shape of a sphere approximately 2 inches in diameter to a dome-shaped stump measuring only 1¼ to 1½ inches in diameter at its base.

Microscopically, there was usually a thin covering over the superior portion of the femoral head that consisted of a tissue surprisingly like hyaline cartilage. This showed flattened small chondrocytes on the surface layer and larger rounded and paired chondrocytes in the deep layer. Between the

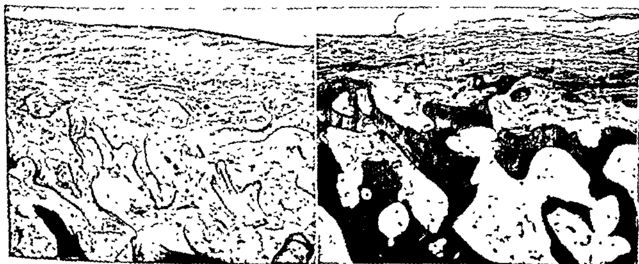


FIG. 5. (*Left*) Photomicrograph of the biopsy specimen shown in Figure 4 in the area indicated by the arrow. The new articular surface consists chiefly of fibrous tissue. The underlying spongiosa shows new bone trabeculae and fibrous marrow. (Hematoxylin and eosin stain.) (*Right*) Photomicrograph showing serial section of the specimen shown at *left*. The intercellular fibrillar structure of the new articular surface consists of loosely woven blackened fibers of reticulin deposited parallel to the surface of the femur. (Wilder's stain.)



FIG. 6. Specimen of the femoral head removed from a hip following a fracture-dislocation complicated by avascular necrosis of the femoral head 29 months after arthroplasty. The new articular surface measured 1 mm. in thickness and had many irregularities and bare spots. (Hematoxylin and eosin stain.) (×5)

flattened cells the matrix consisted of a small amount of faintly pink staining ground substances containing a dense meshwork of fibers of reticulin and collagen. Between the large round cells the matrix consisted of deep blue (azurophilic) staining ground substance and a less dense arrangement of vertical and curving fibers of reticulin In general, the cartilage cells were irregular in shape and always smaller in size than in normal articular cartilage. The portion of the articular surface around the equator of the "shrunken head" consisted mainly of ordinary fibrocartilage. Fibrous tissue, hypertrophied synovial villi, chronic inflammatory tissue and small amounts of fibrinoid were present all around the femoral neck and the rim of the Vitallium cup. (Figs. 6-8)

THE VITALLIUM HIP SOCKET

The repair of the joint following arthroplasty was the same with the Vitallium socket as with the Vitallium mold with the following exceptions: (1) The shoe nails on the convex side of the socket were enveloped in a thin layer of dense fibrous connective tissue, including some fibrocartilage cells; (2) the cotyloid fossa and notch were filled with a cord of dense connective tissue resembling a new ligamentum teres (Figs 9-12)

CHEMICAL COMPOSITION OF THE NEW JOINT SURFACE

Small samples of connective tissue and cartilage, mainly trimmings of the tissues used for histologic sections, weighing approximately 1.0 Gm., were scraped off the bony parts of the specimens of the femoral head from 2 fetuses, 2 adult hips of fresh autopsy subjects and 6 arthroplasties. Chemical analyses were made for total sulfur, hexosamine,* and hydroxyproline (indirectly also collagen which was estimated by dividing the figure obtained for hydroxyproline by 0.132) after drying the tissue to constant weight. (Table 2)

Sulfur. The total sulfur content in milligrams per gram of dry weight of the tissue was 1.4 at 6 months, 3.6 to 4.0 at 1 year, and 4.8 at 4 years. These results suggest that there was a slight increase in concentration of sulfur-containing components of the

* **Hexosamine.** Nitrogenous sugars found in combination with hexuronic acid in all connective [illegible]

saccharides composed of hexuronic acid and a sulfated hexosamine, predominantly galactosamine, fo[illegible]

13 [illegible]

only other scleroprotein to contain this amino acid is elastin which has 2.0%); the concentration of hydroxyproline is a reliable quantitative index of the collagen content of the tissue.

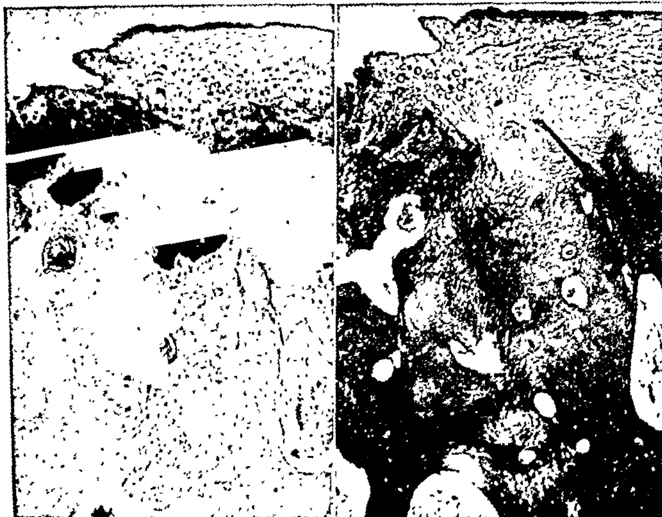


FIG. 7. (*Left*) Photomicrograph of serial section of the area indicated by the arrow in Figure 6. The light staining outer layer of the new articular surface contains small flattened cells with faint pink staining matrix. The deep layer contains large hyalinelike cartilage cells with basophilic and metachromatic staining ground substance. Note the deposits of the new fibrocartilage in the interstices of the trabeculae of new cancellous bone. A new articular cortex can be seen forming beneath the new cartilage. The presence of the cartilage in the interstices of bone suggests that the new cartilage arose from endosteum. (Hematoxylin-eosin and Azure II stain.) (*Right*) Photomicrograph of a serial section of the specimens shown in Figures 6 and 7, *left*. Note the small flattened cells and the abundance of blackened reticulin and collagen fibers in the surface layer and the larger cartilage cells with clear staining ground substance in the deep layer. The bone tissue shows the greatest density of collagen fibers and stains a dark brown color. (*Wilder's method.*)

tissue during healing of an arthroplasty, but the content is never as high as in fetal or adult cartilage. Chemical analyses for sulfate and chondroitin sulfate should give more information about the metabolism of the regenerating articular cartilage.

Hexosamines. In the new soft-tissue covering of the femoral head, the hexosamine content was 2.0 Gm. per 100 Gm. of the dry weight of the tissue at 6 months, 2.0 Gm. at 1 year, 4.9 to 7.4 Gm. at approximately 48 months to 5 years. These observations suggested that the total hexosamine content of ground substance changed very little in the early process of repair of the joint but increased markedly in the late stages, possibly reflecting chondrogenesis.

Hydroxyproline. The quantity of this amino acid indicates the amount of collagen and its building stones in the tissue. The



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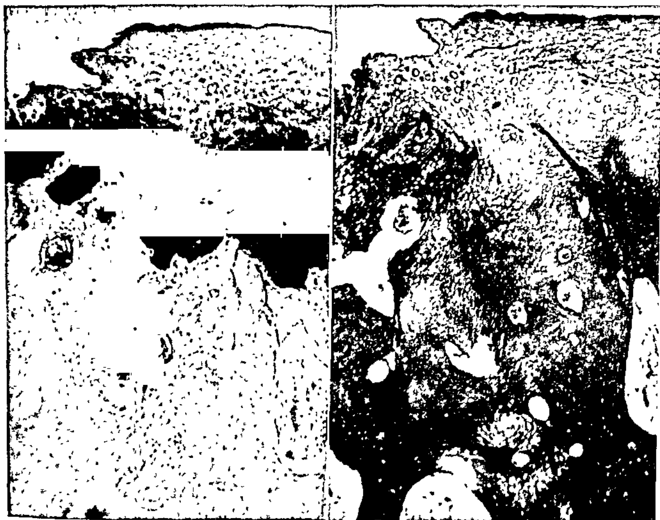


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FIG. 8. (*Top*) Photomicrograph (×3) of a serial section of a specimen first described by Smith-Petersen (S. Clin. North America, Oct., 1947) from an autopsy on a patient *approximately 5 years after arthroplasty* for degenerative joint disease following trauma. The sections of the acetabulum and the femoral head were prepared separately and opposed to show the equal thickness of the cartilage on the two sides of the joint. The new articular surface was approximately 2 mm *in thickness. (Hematoxylin and eosin stain.) (Center)* Photomicrograph (×50) showing the new articular surface of the acetabulum. Note the formation of fibers in cartilage coextensive with the collagen fibers in bone and perpendicular to the surface of the acetabulum. *(Bottom) Photomicrograph of the area of the notch in the femoral head indicated by the arrow* in top illustration. The intercellular fibers pass vertically toward the surface and curve gradually until they spread out parallel with the surface of the head.

hydroxyproline content of the soft tissue of the new articular surface was 26.4 to 40.0 Gm. per 100 mg. of the dry weight of the tissue at 6 months; 41.0 to 44.0 Gm. at 1 year; 58.0 to 97.6 Gm. at 4 to 5 years.

Collagen. Based on the hydroxyproline content of the tissue, the collagen content may be estimated at 200 to 302 Gm. at 6 months, 310 to 333.0 Gm. at 1 year and 440.0 to 739.0 Gm. per 100 mg. of tissue per year at 2 to 5 years. These observations show that the collagen content does not change appreciably in the period between 6 months and 1 year. Both chemically and morphologically the collagen showed an increase in the quantity and the density corresponding to the transformation of thin fibers to coarse fibers in the deep layers of the new articular cartilage after 2 years. The collagen content of aged articular cartilage in a 70-year-old man was 1,715 Gm., more than twice as much as in arthroplasty cartilage after 4 years of healing.

DISCUSSION

An arthroplasty, like a *fracture*, exposes subchondral bone and activates resting connective-tissue cells and osteoblasts having the potency to differentiate into fibrocartilaginous callus. The rate of formation of



FIG 9. Roentgenogram 26 months after hip-socket arthroplasty for degenerative joint disease and avascular necrosis of the femoral head of unknown etiology.



FIG. 10. Roentgenogram of a specimen removed from the joint shown in Figure 9 treated by replacement of the femoral head with a prosthesis. A reversed silhouette of the upper end of the opposite femur is shown in the background to illustrate the amount of bone estimated as (I) removed during the arthroplasty and (II) lost by resorption of cancellous bone during process of repair of the joint. Note the subchondral bone cysts in the interior as well as in the surface of the head.

fibrocartilage was slower in healing arthroplasties than in healing fractures and was reduced to zero wherever their was dead bone beneath the reamed surface of the femoral head. Bare spots on the head have been described previously as "ulcers."[1] Our view is that in these areas a covering never was present and cannot develop over dead bone. Painless weight-bearing was not seen, and it is reasonable to assume that it is not possible without the healing of the joint surface and regeneration of cartilage. However, satisfactory motion was possible but only temporary in our series of cases with dead femoral heads inside the cup. After 1 to 3 years, the results were increasingly unsatisfactory because of pain of increasing severity, and for this reason the patients consented to another operation and supplied the biopsy material described above.

The Nonspecific Reactions to Injury and Repair

The early stages of the healing of an arthroplasty, based on observations in both clinical biopsies and experimental animals, consists of nonspecific reactions, i e., inflammation, fibrinoid degeneration and fibrous-tissue proliferation that characterize all wound healing. The one part of the process, precipitation of fibrinoid, associated with friction and motion of moving connective-tissue surfaces, has not been described previously in material from arthroplasties. The significance of fibrinoid in pathologic physiology of skeletal tissue was presented in detail with the aid of histochemical methods by Urist, Mazet, and McLean, as well as



Fig. 11. (Top) Photograph of an autopsy specimen of the joint of a 60-year-old man who died of a brain tumor 3 years after *hip-socket arthroplasty* for degenerative joint disease resulting from central fracture and protrusio acetabulae. The capsule was circumcised and the head of the femur is shown withdrawn from the Vitallium socket to reveal the new ligamentum teres of fibrous tissue that fills the cotyloid notch and fossa. Anterior superior view. *(Center)* Photograph of same specimen as shown above, as seen from the inferior aspect of the hip, showing the new ligamentum teres of fibrous tissue, the cotyloid notch and the transverse acetabular ligament. *(Bottom)* Roentgenogram of the head of the femur of the specimens shown above. Note the two large subchondral bone cysts in the superior portion of the head and the remodeled trabecular pattern where the bone tissue appears dense on the lateral side of the head.

Monticelli and Bono, in fractures that failed to unite due to insufficient immobilization, excessive necrosis of bone, or sepsis. The resemblance between the tissues found in an arthroplasty and a pseudarthrosis has been recognized by all previous observers.[1,8,9,11,19,21,23]

Factors Influencing the Formation of Fibrocartilage and Hyalinelike Cartilage

Observations upon experimental animals with various types of surgical defects in joints suggest that the articular cortex should be erased in every arthroplasty operation because *the cells with the potency to differentiate into cartilage come from subchondral cancellous bone.* Shands' survey of the literature and his own observations, corroborated by others,[3,13] established two interrelated facts: (1) The most active and complete form of repair of joint surfaces can occur only if there is exposure of the subchondral bone marrow; (2) *the least active* and usually incomplete form of repair occurs in defects which do not penetrate the articular cortex. In the material described in this report new connective tissue appeared to arise from reticular cells* of bone-marrow

* **Reticular Cells.** Connective tissue of the stroma of bone marrow similar to or identical with *fibroblasts having the multipotent* capacity of primitive connective tissue (mesenchyme) for dedifferentiation and redifferentiation (modulation) into specialized connective tissue cells.

(Footnote continued on facing page)

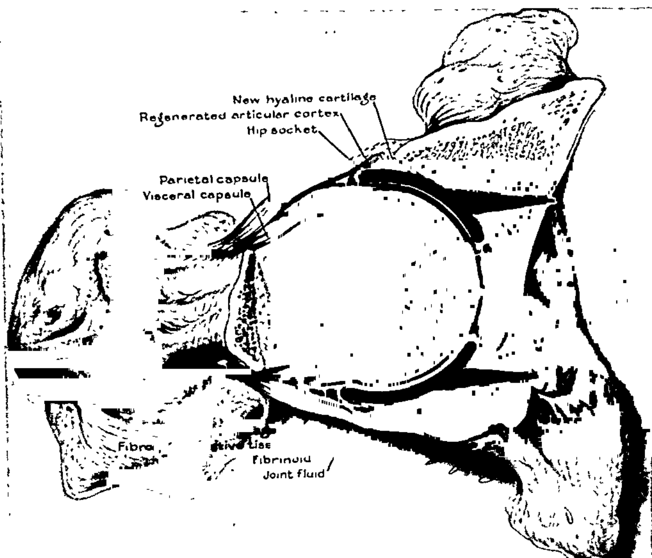


Fig. 12. Artist's reconstruction of an arthroplasty produced with a hip socket. The socket including the shoenails were embedded in an envelope of dense fibrous tissue on all sides except for the inside in contact with the moving head of the femur. The surface of the head was absorbed and reduced in size and replaced with new fibrocartilage and hyalinelike cartilage (Fig. 14). The notch below the center of the socket became filled with a cord of dense fibrous connective tissue, as shown in Figure 11, *top and center.*

stroma, mesenchymal cells surrounding small blood vessels, and from synovial membrane. However, the *small spindle shaped or resting osteoblasts of subchrondral spongiosa* appeared to be the most important of these possible sources of the new cartilage. New fibrous tissue, including synovial tissue, proliferated all around the structure of the joint, but the fibrocartilage seemed to come chiefly from the endosteum of underlying cancellous bone by modulation (dedifferentiation and redifferentiation) of "resting osteoblasts." The capacity of endosteum to produce both cartilage and bone has been described in tissue cultures[7] and healing fractures.[26] New cartilage arose from young connective-tissue cells beneath the synovium

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Endosteum. A layer of connective tissue cells (morphologically a condensation of reticular cells) that forms a sheath around all the bone trabeculae; endosteal cells are small, spindle shaped and slightly basophilic in the resting form in adult bone tissue or large, swollen, polygon shaped and deeply basophilic during growth in young individuals. These cells exhibit the potency to differentiate into either chondroblasts forming cartilage or osteoblasts forming bone.

FIG. 13. Composite photograph of a roentgenogram of gross sections of the two normal heads of the femur from an autopsy of a 68-year-old man who died of disease of the coronary arteries. The right femoral head [illegible]
from 1 to 7. The left femoral head [illegible]
8 to 14. The sections were approxi [illegible]
The location of each section is shown in the diagram in the center of the picture. Note that the old epiphyseal line is clearly distinguishable in Section 11, compared with the epiphyseal lines in Figure 10, where it is absent, and Figure 11, *bottom*, where it is partially resorbed.

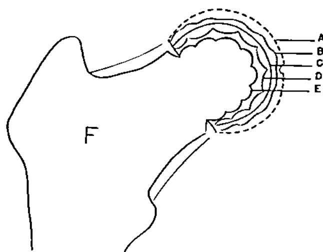


FIG. 14 Composite diagrammatic representation of the 5 steps leading to reduction of the diameter of the femoral head following arthroplasty. (A) Normal femoral head as shown in Figure 11, *top;* (B) after erasure of articular cortex; (C) after 6 months of resorption, remodeling and healing (Fig 3); (D) after 1 year of reconstruction of new articular cortex; (E) after 5 years of remodeling annd reconstruction of new articular surfaces Compare Lines E with the outlines of the femoral head in Figures 6 and 8, *top*. Note that in both instances the old epiphyseal line is absent, indicating that the bone structure of the head in this area had been erased or resorbed and remodeled.

and did not appear to differentiate from adult synovial cells as suggested by many writers.

Remodeling of Bone

The most complete record of the reactions of the femoral head was observed in serial roentgenologic examinations of patients who had had fascial membrane arthroplasties and no cup to conceal the changes in the bone structure. Knight and Speed described rarefaction or "osteoporosis" of the head during the first 3 months after the operation. In some cases, following a period of motion and weight-bearing, the bone trabeculae reappeared with more normal density and a line of condensation of new bone below the articular surface. In other cases, "progressive osteoporosis" developed instead of osteosclerosis, the head and the neck of the femur were absorbed, and the trochanter came to rest on the superior rim of the acetabulum. In other instances, normal bone density was regained and "secondary osteoarthritis" of the hip developed after a period of years. The surface of the femoral head became irregular and sclerotic, and the center of the head showed changes suggestive of infarcts, aseptic necrosis and sequestration of a large area of bone. These changes as seen in the foregoing biopsies were interpreted as part of the process of remodeling of subchondral cancellous bone, and depended on the degree of necrosis of bone or the impairment of the circulation in the femoral head by the disease for which the arthroplasty was done, by the surgical disarticulation of the joint or by a combination of the two (Figs. 13 & 14)

Weight-bearing

Smith-Petersen described an articular cartilage, chiefly of fibrocartilage which in some areas approximated hyaline cartilage, in an arthroplasty produced with a glass mold that was removed and replaced by a Vitallium mold and again examined after 5 years of good weight-bearing. Gibson and Alexander and Gibson described 3 arthroplasties: 2 with "true hyaline-type" cartilage that had been used well for weight-bearing for 3 and 10 years, respectively, and 1 without hyaline cartilage that had not been used for weight-bearing. Badgley performed 13 reoperations and found that the gross appearance of the new cartilage approached normal in 2 cases. In both instances, Badgley did not replace the cup and allowed the patients to bear weight on the new cartilage in order to test the 2-stage mold concept of Smith-Petersen. Fischer-Wasels and Otte and most other observers described arthroplasty cartilage as inferior or imperfect. The impression one gains from reading these reports is that the type of healing and the thickness of the fibrocartilage was proportional to the length of time of healing following arthroplasty. The amount of motion and weight-bearing or function that the joint was subjected to apparently determined how near the patient came to regenerating an organized articular cartilage.

Differences in Articular Cartilage in Arthroplasties and Normal Hip Joints

The structure of the articular cartilage of the human hip is much more complicated than is apparent in ordinary hematoxylin- and eosin-stained sections. To see the internal architecture of the normal adult cartilage, it is necessary to section the head in two planes and examine preparations impregnated with silver to show the relationship between the cells and the fibers of reticulin and collagen.

Sections through the sagittal plane (longitudinal lines of the spherical head) show the fibers in the deep layers widely separated and arranged around large cells in *arcades;* the fibers on the surface layer are densely packed and interwoven between small cells to form a hard shell of proteinaceous material Sections through the transverse plane (latitudinal lines of the spherical head) show large cartilage cells formed within large amounts of hyaline ground substance bound together by coarse bundles of collagen

and arranged in spherical aggregates called *chondrones* by Benninghoff. Between the chondrones and groups of chondrones are interlacing fibrils that pass through the ground substance from one chondrone to the next. The fibers of articular cartilage were interpreted by Benninghoff to be tension resistant. The interfibrillar ground substance, including the masses of round cartilage cells with thick capsules and large envelopes of chondroitin sulfate (metachromatic-staining material), were pressure resistant, like a fluid-filled bladder with elastic walls. An interesting analogy cited by Murray is the structure of an automobile tire, the rubber being the cells or pressure-resisting material and the layers of cord the collagen and reticulin fibers or tension and friction-resisting material. Thus, articular cartilage, like bone, is organized on two levels: cartilage as a tissue and cartilage as cartilages or organs. (See color plate.)

The articular surface found in Case 15 and Smith-Petersen's patient (Fig. 8, *center & bottom*) 5 years after arthroplasty shows vertical fibers curving toward the surface like the arcades of Benninghoff but appears lacking in *chondrones*, the mechanical units of structure of articular cartilage. The chondrones are analogous to osteones of compact bone. The weight-bearing joints of an adult individual consist of compact cartilage compared with the spongy or loose cartilaginous tissue that is formed following arthroplasty. However, it appears from the 2.0 to 3.0 mm. thickness of the new articular surface in Smith-Petersen's 5-year specimen that the hyalinelike cartilage can grow in thickness in some unknown way after 2 years of healing It is generally accepted[12] that true articular cartilage in young growing individuals increases in thickness and renews tissue lost by wear and tear by means of a growth apparatus that functions in two directions. Thus, it differs from epiphyseal plate or skin wherein growth occurs only in one direction. Proliferation of joint cartilage appears to take place from the transitional zone of flattened young mother cells below the free surface. The deep calcified zone is the oldest, and its cells hypertrophy but do not proliferate. In the adult, the superficial cells that are worn away slowly by erosion and pressure during movement are replaced as necessary by some mechanism that seems to have defied elucidation.[6,12]

Chemical Components of the Regenerating Joint Surfaces

The synthesis and the deposition of the components of regenerating articular cartilage were observed with the aid of chemical methods adaptable to small samples of tissue. The structure of the surface layer was so different from that of the deep layer in both regenerating and normal cartilage that it would seem to be necessary in the future to do chemical studies on the two layers separately (split-thickness specimens) rather than on the whole thickness, as was done in this study. The whole thickness of new articular surface showed almost the same proportion of hexosamine to hydroxyproline at all stages from 6 months to 2 years, but morphologically the surface layer showed high concentration of collagen and low concentration of ground substance. The deep layer showed a reverse relationship between collagen and ground substance. The over-all trend of the chemical changes in the new articular surface shows a steady gain in concentration of collagen with a corresponding loss of water, and in this respect it resembled growth and aging changes in skin. The azure-staining components of the matrix appeared after maturation of the fibrocartilage and with differentiation of hyalinelike cartilage and steadily increased in quantity and density between 1 and 2 years. Azurophilia presumably reflects the progress of synthesis of chondroitin sulfate, the characteristic component of cartilage. This requires further study in arthroplasties by means of

newer and improved quantitative chemical methods, including radioactive isotopes.

Surgical Considerations

Theoretically, erasure of all the old cortex of the femoral head is an essential step in every arthroplasty operation, but often in actual practice a small amount of cartilage is allowed to remain on the head. Some of this may survive and function as arthroplasty cartilage. Regardless of whether cartilage remains or foreign cartilage, skin, fascia or a cup is interposed between the raw surfaces of cancellous bone, or whether or not only raw bone remains following arthroplasty, the process of repair is a subsurface phenomenon and depends upon resorption and replacement of subchondral cancellous bone. Phemister observed that biologic membranes, either as free grafts or pedicles, had no significant effect on the process. It would appear that the function of an interposed membrane or a Vitallium cup was merely to sustain the joint space until new joint surfaces could regenerate.

CONCLUSIONS

1. The repair of the joint following arthroplasty was observed to proceed in one of two different pathways. One was seen in patients who had post-traumatic and other forms of avascular necrosis of the femoral head either before or after the arthroplasty. This led to disintegration of the joint, persistent inflammation and an inferior fibrous repair. The other pathway of repair was seen in patients with old fracture of the acetabulum, Marie-Strümpell arthritis, osteochondromatosis, healed Legg-Perthes disease (conditions in which either the femoral head had had or had developed good collateral circulation or in which the devitalized part of the head was removed during the surgical operation). This led to the formation of a new fibrocartilaginous articular surface.

2. The products of repair were fibrinoid and fibrous tissue at 6 months, fibrocartilage at 1 year, and hyalinelike cartilage at 18 months to 2 years.

3. Fibrinoid was precipitated at the beginning of fibrous repair, increased in quantity between 6 and 12 months of healing and gradually diminished in volume afterward.

4. The new fibrocartilaginous tissue and hyalinelike cartilage differentiated from endosteum of the subchondral cancellous bone. The new articular cartilage developed in conjunction with absorption and remodeling of the bone tissue and at the expense of the cancellous bone at the head of the femur. For this reason, the femoral head diminished correspondingly in size in the course of repair of the hip joint following a successful arthroplasty.

5. Painful nodular synovitis was observed in patients with dead bone inside the cup. It is suggested that dead bone should be removed as completely as possible even if it becomes necessary to remove the tip of the trochanter and transplant the gluteus medius muscle tendon distally to make a substitute for the femoral neck.

6. Collagen, hexosamines, various sulfated and nonsulfated mucopolysaccharides and, most important, chondroitin sulfates, are synthesized by differentiating connective-tissue cells during the process of repair of joints; these components require further study in experimental and clinical arthroplasties.

7. The hyalinelike cartilage formed in the repair of the joint surface is like articular cartilage but is not true articular cartilage As the cells are small and paired, the hyalinelike cartilage appears to develop from amitotic division of fibrocartilage cells, presumably under the influence of pressure of weight-bearing on the surface of the joint. Arthroplasty cartilage did not show the complex organization of the cells as *chondrones* and fiber bundles as *arcades of Benninghoff* as in normal adult articular cartilage.

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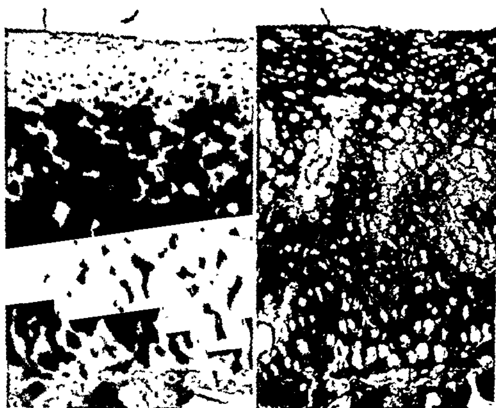
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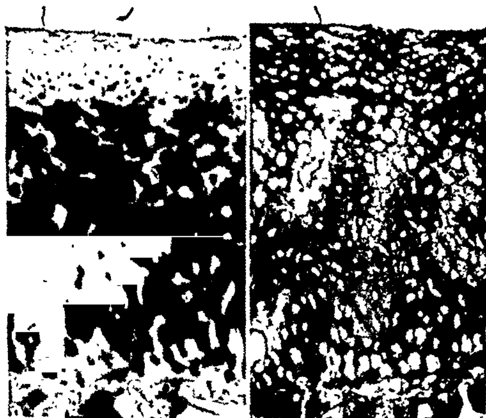
(*Left*) Kodachrome photomicrograph of a sagittal section of the articular surface of the femoral head (longitude lines) from an autopsy specimen of the hip of a 70-year-old man. The cartilage cells in the deep layers are large and surrounded by spherical area of matrix rich in metachromatic staining azurophilic ground substance. The cartilage cells in the surface layer are small and flattened, and there is very much less ground substance and very much more fibrous material between them. (Hematoxylin = eosin and Azure II stain.)

(*Right*) Kodachrome photomicrograph of a serial section of the same specimen shown on the left. There are large bundles of blackened fibers passing vertically and diagonally between the large cartilage cells of the deep layer. The surface layer consists of a dense matting or shell composed of argyrophilic fibers and small flat cells. The larger masses of cells surrounded by blue-staining capsules of matrix are the *chondrones*. This arrangement of chondrones and the fibers resembles the structure of an automobile tire, in which the cells serve as the rubber and the fibers serve as the cord. (Wilder's stain.)

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Reparo del Superficies Articular post Arthroplastia Coxal

Summario in Interlingua

Observationes in 15 re-operationes e un necropsia, insimul con un revista del litteratura, revelava le paucitate de nostre cognoscentias de lo que occurre in le capite femoral intra le cuppa de vitallium. Le reaction del structura ossee al operation arthroplastic (que es un forma special de vulneration) e al reparo del articulation post le operation esseva celate per le cuppa. Le aspecto pathologic variava naturalmente con le morbo, le etate del individuo, le typo del operation, le periodo del resanation, etc. Tamen, le processo del reparo non variava. Al contrario, simile al majoritate del altere reactiones pathologic, illo esseva un processo stereotype. Le apparentia macroscopic o radiographic del capite femoral esseva determinate per le quantitate e le sito de osso necrotic. Le apparentia microscopic consisteva de grande o micre quantitates de osso morte con histos initialmente fibrose, postea fibrocartilaginose, e finalmente cartilaginoide. In le presente studio nos ha observate duo vias sequite per le processo reparatori: (1) Characterisate per le disintegration del capite, con le resultato inevitabile de non-successo del arthroplastia, e (2) characterisate per le persistentia del capite, lo que es essential pro le functionamento satisfactori del articulation coxal. Le patientes describite in iste studio esseva tractate per arthrodese o un operation revisional pro le un o le altere de duo rationes: (1) Dolor, contractura de adduction, e reduction del longor del gamba per un a duo pollices, in le presentia de un bon grado de mobilitate del articulation coxal, e (2) recurrentia de ankylose con o sin dolor in le articulation coxal. Le patientes qui requireva re-operationes a causa del prime de ille rationes exhibiva disintegration del capite femoral. In le patientes qui requireva re-operationes a causa del secunde ration, i.e., osteoarthritis o coxa rheumatoide, le capite femoral non esseva disintegrate e exhibiva—ben que a grados minus complete—un reparo del superficies articular simile a illo vidite in specimens necroptic ab casos de arthroplastia successose. Durante que il esseva impossible provar que subchondral cystes ossee esseva absente ante le arthroplastia o non se haberea disveloppate in le curso del tempore sin le effectuation del arthroplastia, il pare que le processo del reparo del articulation esseva frequentemente associate con le formation de fibrocartilaginose cystes de osso subchondral, simile a illos vidite in osteoarthrosis. Le nove articulation resimilava un pseudoarthrose e esseva revestite de fibrinoide e plenate de un fluido grossiermente simile a fluido bursal. Le complexe organisation de fibras in arcadas e de cellulas in le chondrones de normal cartilagine articular non occurreva in le histo cartilaginoide de arthroplastias.

20

Functional Fixation of Femoral Neck Fractures; Telescoping Nail Technic*

William K. Massie, M.D.†

Intracapsular fractures of the femur have long presented a problem in treatment. Fifty years ago nonunion seemed the inevitable result. The laity learned to accept the inevitable, and the profession took refuge beneath the canopy of misconception when the results were less than optimum. Dickson[8] credits Senn (1901)[26] with a perspicacity only recently appreciated when he wrote:

> We are . . . justified . . . in asserting that the only cause for non-union in the case of an intracapsular fracture *is to be found in our inability to maintain coaptation and immobilization* of the fragments during the time required for bony union to take place.

The author accepts this as literally true, and during the course of this chapter proposes to outline briefly (1) the major advances in the past 50 years forming the basis for the proposed treatment; (2) internal fixation based on the mechanical principles herein discussed; (3) a statistical comparative analysis of 21 displaced fractures held with a rigid trifin nail and 57 similar fractures held with an adjustable length appliance.

HISTORY

Royal Whitman[31] voiced a sustained objection to the pessimistic attitude in the treatment of this fracture which had gripped both the profession and the laity alike. By adequate reduction and prolonged cast fixation he obtained healing in 89.2 per cent of the cases, but others using this method have been unable to duplicate these results. Smith-Petersen *et al.* (1931)[28] introduced the triflanged nail as an effective means of internal fixation by the open method, and *Johansson (1932)[13] simplified this technic* by introducing the cannulated triflanged nail inserted without open reduction. Though these methods lowered morbidity and mortality, they failed to lower materially the nonunion rate. Leadbetter (1933)[17] standardized the manipulative reduction of this fracture. Pauwels (1935)[22] summarized and emphasized the oft-repeated observation that abduction-type fractures (Type 1) heal readily, and that as the fracture line approaches the vertical in the anteroposterior roentgenogram the rate of pseudarthrosis increases. Cotton (1938)[7] outlined a manipulative method of obtaining

* The author acknowledges the invaluable help of Dr. Karl Lange, Professor of Physics, School of Engineering, University of Kentucky, not only for partially designing and producing the appliance here reported but for checking and testing the mechanical principles involved.

† Lexington, Ky.

an abducted position prior to internal fixation. Eyre-Brook and Pridie (1941)[10] emphasized the importance of the valgus position and, like Pauwels, showed the relation between the fracture angle and the rate of nonunion. Farkas *et al.* (1947)[11] from an anatomic study of the trabecular arrangement of the femur drew attention to the importance of this system in femoral neck fracture healing. Inman,[12] in the same year (1947), determined both by theoretic computation and experimental investigation that the medial trabeculations, so obvious in every anteroposterior roentgenogram, indicated the direction of the reacting force (weight-bearing stress) exerted on the hip in the frontal plane, irrespective of the position of the pelvis. Key (1932),[15] Charnley (1948)[4] and Eggers *et al.* (1949)[9] demonstrated the enhancing effect of contact-compression on bone healing. Now a firm mechanical basis supported the clinical impression of Pauwels, Cotton, Leadbetter, McElvenny[20] and others that an intracapsular fracture placed in the valgus position heals readily. A fracture line placed perpendicular to the medial trabeculations is subjected only to a compression force without any shearing component which would tend to retard healing. L. D. Smith (1953)[27] was unable to reproduce any of the typical intracapsular fractures by either direct pressure or falling pressure on the head and the neck in the frontal plane. However, when the neck was subjected to a torsional stress similar to that exerted normally by the external rotators of the hip, typical fractures were produced with a falling pressure only one ninth that required to produce a fracture through the head or trochanter in the frontal plane. Both Smith[27] and Linton (1949)[18] emphasized that the initial displacement in these fractures was usually an external rotation of the distal fragment and relative backward displacement of the proximal fragment, identical to the early deformity so commonly seen in slipped upper femoral epiphyses Thus, attention was focused on the equal importance of reduction of this fracture in the anteroposterior and the sagittal planes.

The vascular supply to the femoral head and neck has been subjected to close scrutiny. The role of the arterioles of the ligamentum teres was thought to decrease with age (Kolodny 1925;[16] Zemansky 1928[33]), but with improvement in investigative technics this supposition has been refuted. Wolcott (1943)[32] found a patent ligamentum teres artery in 80 per cent of adults, and this is supported by the work of Tucker (1949),[30] Trueta *et al.* (1953)[29] and Judet *et al.* (1955).[14] The damage to the femoral neck vascular supply is proportional to the degree of original displacement of the fragments. Subsequent head and neck shortening and deformity are due, in part at least, to this initial vascular damage. The recent studies of Boyd and Calandruccio[3] using radioactive P32 both clinically and experimentally indicate that the initial vascular damage determines almost wholly the eventual outcome. Thus, if the initial damage is severe, though healing may ensue, the "creeping substitution" is so slow and incomplete that a poor clinical result is inevitable. However, Compere *et al.* (1942)[6] concluded from dog experiments that the rate of avascular necrosis was greatly enhanced by poor immobilization of the fragments during healing. The pathologic analyses of Santos (1930)[24] and later Sherman and Phemister (1947)[25] suggest that a compromise position is probably more accurate. The latter believed that the vascular damage was completed at the time of injury but that the "presence or absence of impaction, the accuracy of reduction and fixation" definitely enhanced union and this union was followed by complete reconstitution of the head. *During the period of replacement the head is made increasingly susceptible to weight-bearing trauma; the presence or the absence of such trauma largely determines the eventual incidence of arthritis.* They concluded that though a completely avascu-

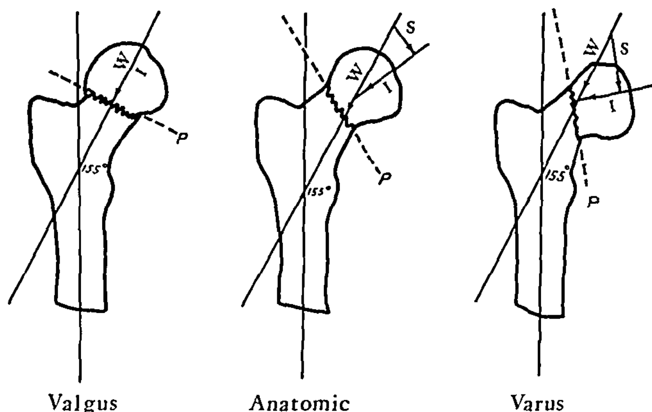


FIG. 1. Adequate alignment in frontal plane. (*Left*) The proximal fragment is placed in sufficient valgus to bring the plane of the fracture perpendicular to the weight-bearing axis of the femur indicated by the vector force (W), which is always parallel to the medial trabeculations and at approximately 155° with the long axis of the femur. The impacting force (I) is always exerted at 90° to the plane of the fracture and, therefore, coincides with the weight-bearing axis. No shear is exerted at the fracture site.

(*Center*) The proximal fragment is replaced in the anatomic position. The fracture line is not perpendicular to the weight-bearing axis (W); therefore, the impacting force (I) no longer coincides with the weight-bearing axis (W). Shear (S) proportionate to the divergence in the weight-bearing vector (W) and the impacting vector (I) is applied to the fracture. However, if the coefficient of friction produced by the irregular opposed surfaces equals the coefficient of shear (S), the effect of this force is eliminated. The coefficient of friction is increased by forceful impaction of the fragments at the time of reduction

(*Right*) When the proximal fragment is left in varus, the divergence of the weight-bearing axis (W) and the impacting force (I) is greatly increased. Shear (S) at the fracture site is so great that, irrespective of the fixation appliance and the coefficient of friction, this fracture remains unstable, tending constantly to be completely displaced. Nonunion is almost inevitable.

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MECHANICAL BASIS FOR THE FIXATION ADVOCATED

Every uncomplicated fracture should heal if optimum conditions are provided. Occasionally, such conditions are not to the best interest of the patient as a whole, and in such circumstances nonunion in any bone is

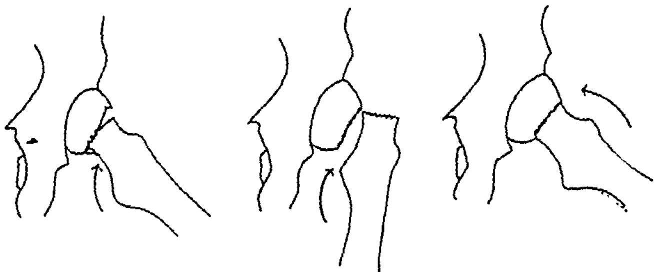


FIG. 2. Adequate alignment, sagittal plane. (*Left*) Intracapsular fractures result from a torsional force exerted on the femoral shaft, which is converted to an angular force exerted on the femoral neck in the sagittal plane. When this force is insufficient completely to displace the neck anteriorly, impaction of the neck posteriorly and separation anteriorly result in the so-called intermediary stage of Linton. This simulates closely a partially slipped epiphysis. (Redrawn from Linton.[16])

(*Center*) When the angular force is greater, the neck is completely displaced anteriorly.

(*Right*) Adequate reduction in the sagittal plane of an intracapsular fracture requires impaction of the fragments anteriorly by forced internal rotation of the femoral shaft. Any residual tilting of the neck anteriorly results in instability. Every attempt of the patient to flex and rotate externally the extremity from the supine position tends further to exaggerate this deformity.

acceptable. Though femoral neck fractures vary in many details from other fractures, in general the three basic principles of fracture treatment—adequate alignment, adequate apposition and adequate immobilization—apply and, if applied, healing will result consistently.

Adequate Alignment

Adequate alignment of this fracture in the anteroposterior or the frontal plane is described clearly by Friedrich Pauwels[22] (Fig. 1). When the proximal fragment is placed in a valgus or an abducted position (Fig. 1, *left*), the reacting force vector is converted almost wholly in the functional hip into an impacting force, and shear is eliminated. When the proximal fragment is replaced in the anatomic position (Fig. 1, *center*), the component of shear increases in proportion to the angle of the fracture and the irregularity of the fractured surfaces. When the proximal fragment is placed in varus or adduction (Fig. 1, *right*), the reacting force vector is converted almost wholly into shear, and, irrespective of the type of fixation, the fracture remains quite unstable.

The alignment of the fragments in the *lateral* or the *sagittal* plane is *equally important*. Linton has demonstrated an intermediary stage (Fig. 2) in the production of this fracture, in which there is incomplete anterior rotation of the shaft producing a deformity similar to the partially slipped upper femoral epiphysis (Fig. 3). With more complete external rotation, the shaft is thrust completely anterior, and the head assumes a relative posterior displacement (Fig. 4). In reduction there must be *forced* internal rotation of the shaft, thus placing tension on the posterior capsule and impact-

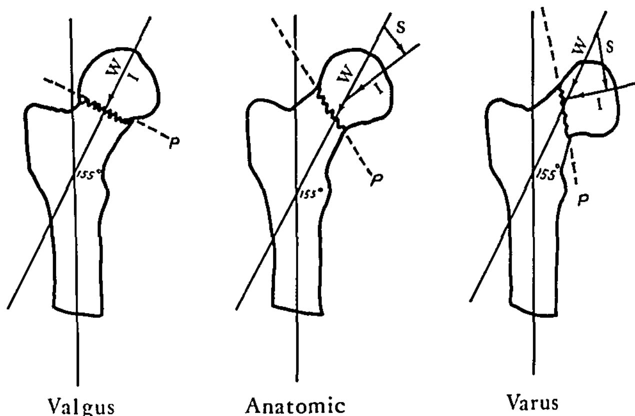


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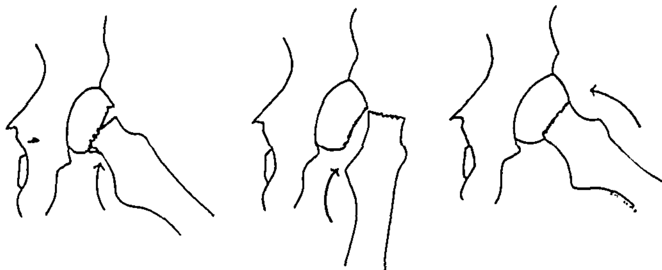


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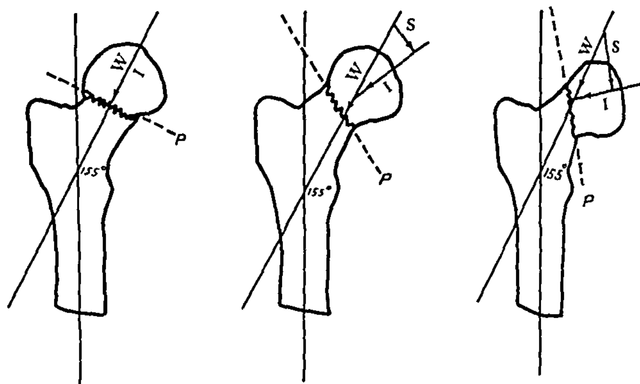


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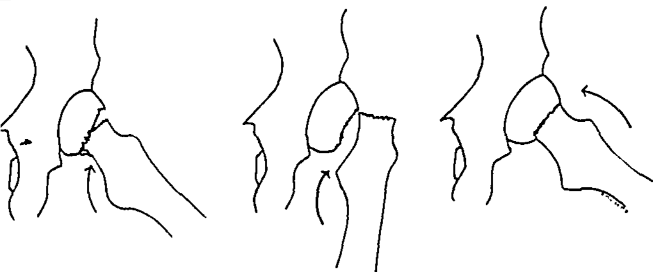


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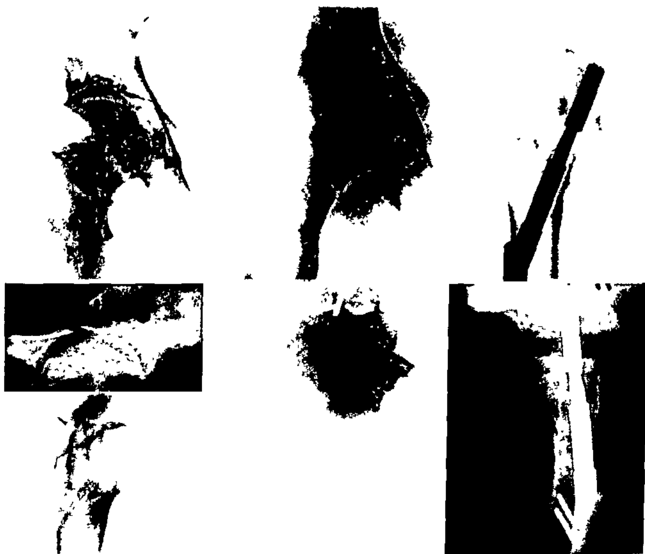


FIG. 3. This illustrates an intermediary fracture described by Linton in which the alignment in a routine anteroposterior view is unchanged but in the lateral view the separation of the neck anteriorly and impaction posteriorly are clearly visible. The instability of the fracture is demonstrated by the separation of the fragments which occurred when an attempt to derotate the fragments was made. Had this fracture been treated by observation alone or the application of a single screw without correction, it could easily have been displaced completely.

ing the fragments in this plane (Fig. 12). Inadequate reduction in this plane results in instability comparable with the varus position in the anteroposterior plane (Fig. 4).

Adequate Apposition

Adequate apposition of the fragments is illustrated in the classic experiments of Eggers, Shindler and Pomerat to demonstrate the effect of contact-compression on bone healing. A flap of bone in a rat's skull compressed by an elastic pull to one side creates distraction on the opposite side. Bone healing was delayed when neither compression nor distraction resulted, accelerated when compression resulted in good apposition of the fragments, and prevented when the fragments were distracted. Compression has not been shown to accelerate osteoblastic activity in tissue culture (Rose & Shindler, 1957). When the compression force was excessive, healing resulted but was retarded. To obtain impaction of the fragments in femoral neck fractures and



Fig. 4. A 71-year-old female with a fracture-shaft angle of 30°. Anatomic reduction in the anteroposterior view was obtained. Note the *incomplete reduction in the lateral view*. The nail was inserted slightly high on the shaft, so that the barrel does not rest on the medial trabeculations. Therefore, the nail impaled the proximal fragment in the upper outer quadrant or weight-bearing portion. This is highly undesirable and could have been avoided by a lower insertion of [illegible] valgus. However, the sagittal [illegible] bearing was postponed 9 mont[illegible]

have this impaction maintained by normal muscular tension seems to provide the optimum apposition to enhance union (Fig. 5).

Adequate Immobilization

Adequate immobilization of the fragments seems to be attained best by the application of Inman's vector analysis of the hip in the *frontal* plane (Fig. 6). The force developed by the abductor muscles reacts on one end of a lever arm to the weight of the body at the center of gravity on the other end. The fulcrum is the center of rotation of the femoral head. Thus, when standing on one leg, the pressure exerted on the hip is the sum of the two respective forces—the abductor muscles times their lever arm, and the body weight times its lever arm (Fig. 6). The resulting force is least when the center of gravity is brought directly over the center of rotation of the hip and greatest when the pelvis is allowed to tilt downward

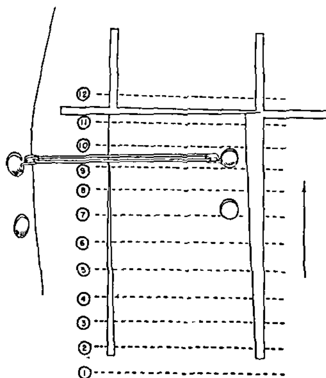


Fig. 5. Adequate apposition. Showing manner of serial sectioning from behind forward (in direction of arrow). Experiment on a rat's skull. An elastic pull on a bone flap creates compression on one side (*left*) and distraction on the other (*right*). Bone healing was delayed in the saw cuts, where neither compression nor distraction resulted (Line 12); accelerated where compression resulted in good apposition (Line 10); and prevented where distraction resulted. When the compression force was excessive (Line 11), healing was retarded by early necrosis of the trabeculations. (Eggers, Shindler and Pomerat[9])

on the contralateral side lengthening the lever arm. It is rarely less than 2.5 times the body weight and may exceed 4 times the body weight. Though it varies with changes in the position of the pelvis, it is applied at a constant angle with individual variations from 151° to 163° to the long axis of the femur, which is at all times parallel to the medial trabeculations. Therefore, if the fracture line could be altered by manipulation to a plane perpendicular to the medial trabeculations, and this position could be maintained by an appliance inserted parallel to these trabeculations, shear would be eliminated If, now, this appliance should have a telescoping length, it would permit both initial impaction of the fragments at operation and subsequent impaction by muscle pull. Often it is impractical to convert each fracture line to a position perpendicular to the medial trabeculations, but even slight conversion to permit impacting the superior lip of the distal fragment into the proximal fragment and the support of this valgus position by the medially displaced medial lip of the distal fragment, as advocated by McElvenny,[20] would eliminate all effective shear. This is demonstrated graphically by applying pressure at 155° to a simulated fracture held by a sliding nail (Fig. 7). The fragments are impacted as the nail shortens. When this identical fracture is held by a rigid nail in the conventional position, there is a tendency to force the proximal fragment into varus. The substitution of a nailplate greatly increases the resistance to this stress, but it does not alter it. *A nailplate with a telescoping feature inserted at an angle less than the weight-bearing axis (155°) must resist an angular stress which would tend to prevent telescoping of the nail by increasing friction between the nail and the nail sleeve.*

A rigid nail inserted at 155°, if not supported by a lateral plate, tends to drop out of the proximal fragment by virtue of its own weight (Fig. 8), but, if fixed with a plate, any subsequent absorption of the neck will result in penetration of the joint by the nail (Fig. 9). Therefore, it should be collapsible or have a sliding adjustable length, as emphasized by Pugh,[23] Badgley[1] and Luck.[19]

A nail inserted at 155° to the femoral shaft must enter the bone from 2½ to 3½ inches below the lateral projection of the greater trochanter and rest on the medial trabeculations of the neck. This requires a nail of average length measuring from 6 to 6½ inches. Also, since the nail is collapsible and will not tend to erode through the proximal fragment into the joint, it can be inserted up to the cortex of the head fragment,

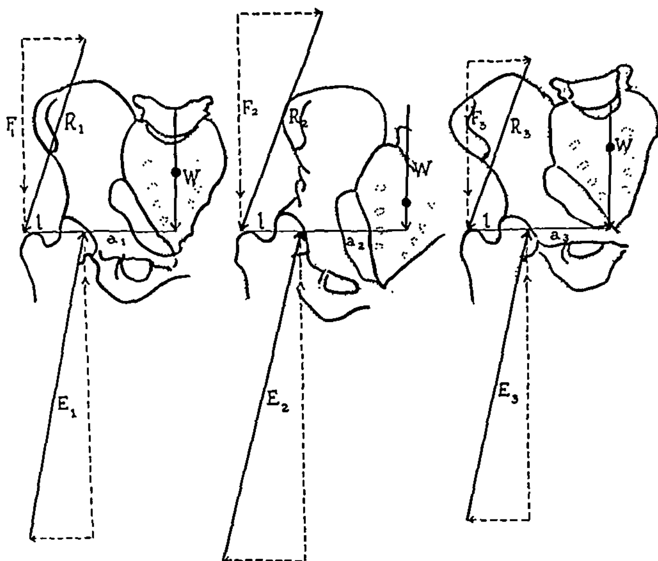


Fig. 6. Adequate immobilization. Inman's vector analysis of the hip in the frontal plane. Note that the resultant force (E) corresponds precisely with the weight-bearing force illustrated by Pauwels (Fig. 1). Both are drawn parallel to the medial trabeculations of the femur. The force developed by the abductor muscles reacts on one end of a lever arm to the weight of the body at the center of gravity on the other end. The fulcrum is the center of rotation of the femoral head. Thus, when standing on one leg, the pressure exerted on the hip is the sum of the two respective forces, the abductor muscles times their lever arm and the body weight times its lever arm. The resulting force is least when the center of gravity is brought directly over the center of rotation of the hip and greatest when the pelvis is allowed to tilt downward on the contralateral side lengthening the lever arm. Though it varies with changes in the position of the pelvis, it is applied at a constant angle with individual variations from 151° to 163° to the long axis of the femur, which is at all times parallel to the medial trabeculations.

thus ensuring maximum purchase (Fig. 10).

Ideally, the nail in the anteroposterior plane should penetrate the proximal fragment inferiorly or near the center (Figs. 10 & 11), but this position is determined by the degree of correction into valgus position and by the initial angle of the neck. In the sagittal plane it should be placed centrally or slightly posterior to the mid-line to offset the tendency to backward rotation of the proximal fragment (Fig. 12). The bending moment of the nail resists this displacement,

and the trifins resist rotation in the third plane. Appliances which obtain their sole purchase on the distal fragment by passing through the lateral cortex of the distal fragment in the subtrochanteric region, where it is relatively thin (nails without plates, Knowles and Moore pins), sacrifice stability in the plane in which the original stress producing the fracture was exerted. Such devices can and do provide adequate fixation in controlled circumstances, but, if sufficient stress is applied inadvertently in either plane, mobility of the fragments is permitted and delayed union or nonunion results.



FIG. 7. Both models are built to scale and are mounted identically in anatomic position with a femoral axis inclination of 10°. Pressure is exerted by the lever set at 165° with the vertical or 155° with the femoral shaft. Double exposure demonstrates only compression at *left*, which utilizes a sliding nail-plate appliance inserted at 155°, but at *right* a similar force applied at the identical angle against an identical "fracture line" shows shearing tendency when an appliance is inserted at less than 155° (140°). The identical component of shear is present in both models, but at *left* it is overcome by the impacting force represented, while at *right* the rigid nail opposes this impacting force and allows shear to predominate. When a plate is attached to the nail, the head can no longer drop into varus, but impaction is resisted until the nail has eroded through the cortex of the proximal fragment and penetrates the joint



Fig. 8. A 70-year-old female—fracture-shaft angle of 45°—flanged nail inserted at 160° in the anteroposterior view and slightly posterior in the lateral view. The weight of the nail at this angle allowed it to back out partially. If it had been fixed laterally with a plate, it might have penetrated into the acetabulum as the neck shortened. (*See* Fig. 9.)

Results of Fixation of Intracapsular Fractures

These results are shown by a comparative analysis of two series treated by the author. Twenty-one consecutive displaced but otherwise uncomplicated fractures (no pathologic fractures were included) were held with various rigid appliances inserted at 155° angle. Then a second consecutive series of 57 similar fractures were immobilized with a sliding or telescoping type of appliance. Though the rigid nail series was the original group, the length of follow-up actually has been shorter than the subsequent sliding nail series, since the percentage returning for study was less (Table 1). No case has been included in either series on which a roent-

Table 1. Length of Follow-up

	Sliding		Rigid	
	No.	%	No.	%
1-2 yrs.	23	40	8	35
2-3 yrs.	17	30	7	33
3-6 yrs.	17	30	6	32
Total	57	100	21	100

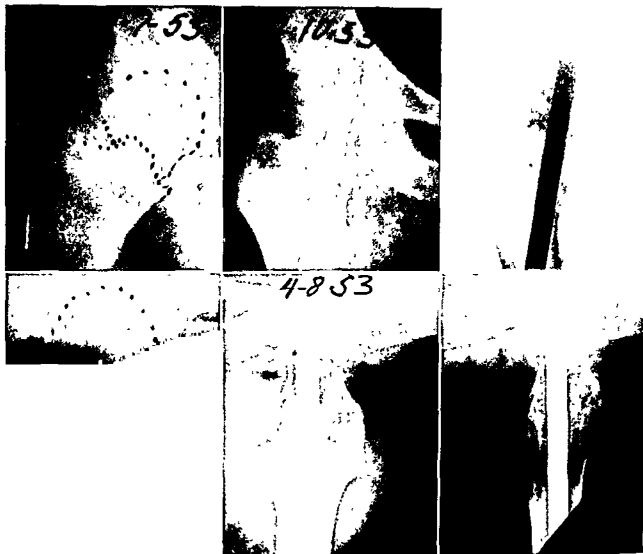


Fig. 9. An 83-year-old female with a fracture-shaft angle of 50° held with a flanged nail and screw buttress. The nail was placed in satisfactory position at 155° but posterior in the head. It was driven to the cortex of the head, and subsequently it eroded through the head due to lateral fixation. It was symptomatic and required removal, a procedure rarely indicated with the sliding nail, because there is no tendency for protrusion into the acetabulum

Table 2. Fracture Angle

	Sliding No	Sliding %	Rigid No.	Rigid %
Fracture-Shaft 60° (Pauwels' No. 1)	1	2	1	5
Fracture-Shaft 60-40° (Pauwels' No 2)	47	82	13	62
Fracture-Shaft under 40° (Pauwels' No 3)	9	16	7	33
Total	57	100	21	100

Table 3. Age Incidence

	Sliding No.	Sliding %	Rigid No.	Rigid %
Under 40 yrs.	1	2	0	0
40-49 yrs.	4	7	1	5
50-59 yrs	4	7	3	14
60-69 yrs.	10	17	8	38
70-79 yrs.	25	44	5	24
80-84 yrs.	12	21	3	14
85-89 yrs	1	2	0	0
90-95 yrs.	0	0	1	5
Total	57	100	21	100



FIG. 10 A 76-year-old male with a fracture-shaft angle of 35°. The head is overcorrected into valgus and impacted at operation (compare with the two views taken at operation, 10-8-54, before impaction). The nail is driven to the cortex. Measurable neck absorption is noted (compare 10-8-54 with 2-7-55), but there is no further penetration of the nail head The nail is correctly placed in the lateral view but is too high in the anteroposterior view. The barrel should rest on the medial trabeculations, which would place the nail lower in the head. The patient is asymptomatic, and recent roentgenograms show firm bony union.

genographic examination 1 year after operation was not obtained. The estimated angle of the original fracture is tabulated in Table 2. The average patient age in the sliding nail series was slightly older (Table 3). The rate of bone healing is also an estimate, since follow-up roentgenograms were taken at only bimonthly intervals (Table 4). When on macrofilm (direct enlargement with 0.3-mm. focus) the image showed continuous trabeculations across the original fracture line, healing was assumed to be complete.

TABLE 4. TIME REQUIRED FOR ROENTGENOGRAPHIC HEALING

	Sliding		Rigid	
	No.	%	No.	%
2 mos.	4	7	0	0
4 mos.	18	33	7	34
6 mos.	15	26	8	38
Nonunion	5	8	5	23
Slipped nail	1	2	1	5
Delayed union	6	10	0	0
Questionable*	8	14	0	0
Total	57	100	21	100

* Re-ray interval too long to justify conclusion



FIG. 11. An 80-year-old female with a fracture-shaft angle of 35°. The sliding nail is placed properly in both the anteroposterior and the lateral views. It could have been inserted deeper into the head for added purchase. The fracture was overcorrected, and impaction was obtained in 4 months Twenty-five per cent weight-bearing was permitted during convalescence—the patient could not be made ambulatory otherwise—and full weight-bearing in 4 months.

In two of the sliding nail group such trabeculations were noted on the first bimonthly roentgenogram, but due to the original impaction these trabeculations may have been merely overlapping trabeculations. As noted in Table 4, unmistakable healing was achieved between 4 and 6 months postoperatively. Those with no evidence of healing in 6 months progressed to nonunion. Though no secondary procedures have been done on either series reported, it is now the practice of the author to alter treatment, usually by additional fixation or more careful supervision, if a fracture line is at all visible 4 months postoperatively. The initial impaction apposes the fragments sufficiently so that healing is accelerated considerably.

Bony union was obtained in 15 (71%) of 21 patients fixed with a rigid nail. One



Fig. 12. A 58-year-old female with a fracture-shaft angle of 45°. There is overcorrection of the proximal fragment, and the sliding nail is inserted deep into the head. A lower position on the shaft with the barrel resting on the medial trabeculations is preferable. Bony union is present; also full range of motion without a limp. Though there is no evidence of avascular necrosis in these views, a subsequent roentgenogram taken in November, 1956, does show a localized increased density immediately above the nail. The nail was removed. The patient remains asymptomatic.

nail slipped before bony union could be expected to result, and a prosthesis was inserted. Five (24%) developed nonunion. Two of these latter were also complicated by a serious infection beginning 1½ and 3 months postoperatively, which resulted in removal of the fixation. In contrast, 51 (90%) of 57 patients in the sliding nail series developed bony union. One nail slipped in the first 48 hours due to faulty application, and 5 (9%) developed nonunion. All these exhibited some degree of avascular necrosis, *but in each there was additional and sufficient reason for the nonunion.* In three, the nail had been placed anterior to the mid-line in the lateral plane. Originally this was not considered to be so serious an error of technic. The head fragment is routinely fragmented or compressed posteriorly and, therefore, tends to displace

posteriorly. When aided by the anterior placement of the nail, sufficient motion is maintained to delay union. This technical error should be avoided easily, but, if the nail is placed before it is noted, it seems best to insert one or two Knowles pins for added security rather than reinsert the nail. The fourth nonunion developed a delayed infection requiring fixation removal prematurely. The fifth patient was not seen after discharge on the eighth hospital day until 3 years later, when she returned in response to repeated requests for a follow-up examination. She had walked continually since discharge, and, though she had some pain and restriction of motion, she thought it only a "touch of arthritis." There was complete avascular necrosis with nonunion, though the head fragment was held in its original position by the nail that had telescoped completely (Table 5).

The obvious contrast between these two series deserves analysis and forms the basis of this presentation. The means of reduction, the angle of application of the nail and the operator were all constant for the two series. The type of patient, though common for both series, presents a factor influential in the results. Seventy-five per cent of the patients were referred from smaller communities at considerable distances (50-150 miles). Transportation was usually by ambulance. Half of the patients could not return for bimonthly roentgenograms as requested. Some of the follow-up roentgenograms have been obtained only after repeated requests to patients to return. Many of the patients began to walk at their own discretion. Economically, it was impossible to keep these patients under closer surveillance. Under such conditions the surgeon either must take refuge in the flimsy excuse of "lack of patient co-operation" or so immobilize the fracture that *it will heal despite lack of co-operation from the patient.* These two series illustrate the results of these two philosophies. The single important mechanical difference in the two series was the *inability to impact at operation the fragments in the rigid nail group,* since, as stated above, without a telescoping appliance the nail either will be driven into the acetabulum or allowed to back out of the distal fragment. However, this fact denied the application of two of the three basic principles of fracture healing—adequate apposition and adequate immobilization. Fragments impacted continually are immobilized far more

TABLE 5. RESULTS AND COMPLICATIONS

	Type of Nail							
	Sliding				Rigid			
	No.		%		No.		%	
Bony Union:								
No complications	41		72		8		38	
Avascular, severe	6		10		0		0	
Necrosis, focal	2		3.5		5		24	
Sepsis, mild	1		2		0		0	
Nail penetrating acetabulum	1	51	2	89 5	2	15	9.3	71.3
Nonunion:								
No complications	0		0		1		5	
Avascular, severe	3		5		2		9.3	
Necrosis, focal	0		0		0		0	
Sepsis and avascular necrosis	2		3 5		2		9.3	
Slipped nail	1	6	2	10.5	1	6	5	28 6
Total		57		100		21		100

completely than can be attained by any means of fixation alone. Supervised weight-bearing in the early postoperative period was attempted in a few of the rigid nail group to obtain impaction, but this is precarious and only partially effective.

Infection complicated three of the five nonunions in the rigid nail series. It is significant to note that in each case infection was delayed 6 weeks to 3 months and, at least in part, resulted from incomplete fixation at the fracture site, which renewed continually a hematoma infected subsequently. Two changes have been made in the control of these patients in the past 4 years which seemingly have controlled completely this complication. Antibiotics, which originally were used prophylactically routinely, are no longer employed unless a wound culture provides a specific organism. Secondly, a posterolateral incision utilizing only the fascial planes is made. This reduces hematoma formation and permits adequate dependent drainage.

Avascular Necrosis Rate

The avascular necrosis rate in the two series must be regarded as incomplete, since less than 60 per cent of the cases have been followed for 5 or more years. Nevertheless, the two series can be compared since, as noted in Table 1, the follow-up period is quite comparable. Eight (14%) of the sliding nail group with bony union developed avascular necrosis, 6 moderately severe. In the rigid nail series, 5 (24%) developed avascular necrosis; 4 (19%) were severe. In the group with nonunion the percentages seem to be significant. In the sliding nail group 5 (100% if the slipped nail is excluded) and in the rigid nail group 4 (80% if the slipped nail is excluded) developed necrosis. *This supports the contention that necrosis is a sequela of nonunion.* The total number of avascular changes was 13 hips (23%) in the sliding nail series compared with 9 hips (44%) in the rigid nail group. There were 10 hips (17%) in the sliding nail series and 3 hips (13%) in the rigid nail group that were not displaced completely in the frontal plane, though all hips in both series were displaced in the lateral plane. None of these slightly displaced hips subsequently developed avascular changes. Also, the degree of valgus displacement in reduction did not affect vascularity, since none of the avascular hips was among the group of moderately overcorrected hips. A more critical analysis of this problem must await a longer follow-up period.

TECHNIC

Though a fractured hip is not considered to be a surgical emergency, it seems to be advisable to fix promptly the fracture internally and permit resumption of an antigravity position in elderly patients. Adequate medical evaluation is secured, but rarely does any abnormal finding postpone surgery more than 24 hours. Patients over 90 years of age in good physical condition and patients with senile dementia are considered to be candidates for prosthetic replacements: the former because the time of fracture healing and restriction from weight-bearing occupy an appreciable proportion of their life expectancy; the latter because the inability to follow instructions postoperatively increases the chance of failure. All others are subjected to the following procedure:

1. The legs are extended on a fracture table, the affected leg being held in traction in the long axis of the body and the other leg abducted to permit adjusting the lateral roentgen tube.

2. Moderate traction is applied to both legs simultaneously with the countertraction provided by the perineal post.

3. *The fractured extremity is gripped firmly at the knee and rotated quite forcibly internally.* This displaces the neck posteriorly and places it routinely beneath the proximal fragment. Then the foot is fixed in inward rotation to maintain the position of the femur in internal rotation.



FIG. 13. Traction is applied to both extended legs. The affected leg is held in the long axis of the body. The knee is forcibly rotated internally, and the foot is rotated inward to maintain the position obtained in the hip. Heavy lateral pressure is applied to the femoral shaft immediately distal to the trochanter. Counterpressure is exerted at the knee. The pressure is maintained while traction to the contralateral leg is released.

4. *With counterpressure applied to the medial side of the knee, a sharp medial thrust is given the affected femur immediately distal to the trochanter, and this pressure is maintained while all traction is released from the contralateral leg* (Fig. 13). This produces a slight valgus position of the femoral head, the medial lip of the distal fragment protruding medial to the proximal fragment.

5. Anteroposterior and lateral roentgenograms are taken before the patient is draped. The head must be in slight valgus in the anteroposterior view and must be aligned anatomically in the lateral view. The shaft and the neck in the lateral view should form a straight line. If there is an anterior bow, the leg requires further internal rotation.

6. A 4-inch posterior curvolinear incision is made beginning 1 inch below the inferior prominence of the greater trochanter and passing along the posterior border of the vastus lateralis. The tensor fascia is incised, the linea aspera identified and the vastus lateralis retracted anteriorly with a Bennett retractor. All bleeders can be coagulated. A bloodless approach is routine. The fixation appliance is shown in Figure 14.

7. Beginning 2½ inches below the trochanteric lip, three 7/64-inch drill holes are made ¾ inch apart in a straight line with a motor drill directed at precisely 155° with the shaft (Fig. 15A). The nail with the plate reversed to form an angle of 25° can be used as a guide, or one of many drill guides can be used. The three guide wires are tapped easily into place with a hammer. Much information can be gained by feeling the various densities as the wires are tapped into place. A trial anteroposterior and lateral roentgenogram indicates the wire of choice.

8. A ½-inch hole is reamed along this guide wire with a cannulated ½-inch drill, care being taken to ream only the lateral cortex of the femur (Fig. 15B).

9. The inserter then is attached to the

nail-barrel assembly, the nail is extended to its full 6 inches and inserted along the guide wire to the calculated depth, care being taken to hold the nail bevel parallel to the femoral shaft to ensure proper fitting of the plate. (A modified inserter recently available simplifies this.) A fourth pair of films is taken (Fig. 15C).

10. The 2-inch plate is clipped onto the distal end of the barrel, and, with the impacter, the plate is pushed against the shaft. Two screws are inserted. The position of the nail has not been altered by this maneuver. The fourth pair of roentgenograms, which should now be ready, demonstrates the position of the nail If it does not penetrate to the cortex of the proximal fragment, it is inserted farther with the inserter (Fig. 15D).

11. Finally, with all traction removed from both legs, the distal fragment is impacted firmly against the head or proximal fragment with the impacter, gaining purchase on the plate, which is held firmly to the distal fragment (Fig. 15E). The nail does not penetrate farther because of its sliding quality. A fifth pair of roentgenograms should show complete impaction of the distal fragment into the proximal fragment with the medial lip lying immediately inside the proximal fragment (Fig. 11).

Convalescent Care

Convalescent care of a fractured hip influences the end-result equally as much as the operative fixation. Inadvertent weight-bearing has been stressed as a factor influencing failure. Fixation by the method advocated reduces the deleterious effect of this factor, but this stress is applied in only one of the three planes. Initially, the fracture resulted predominantly from a rotational stress. If by chance adequate internal rotation was not obtained at reduction (Fig. 4) or inadequate purchase was obtained on the proximal fragment, the neck could rotate anteriorly, pulling the nail from the proximal

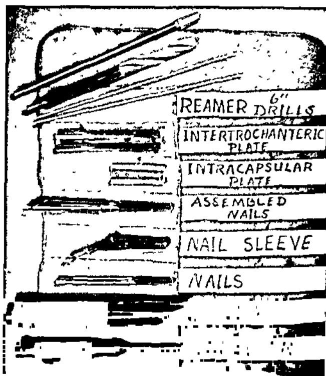


Fig. 14. (1) Inserter screws into the butt of the nail, permitting extension of the nail in the sleeve.

(2) Driver fits into notches in the plate (shown on the sleeve No. 4).

(3) Flanges of the nail vary from 1½ to 2 inches It is cannulated to accept a ⅛-inch drill. It can be locked into the sleeve so that it will glide back and forth but cannot be extracted unless twisted a 90° turn when fully extended.

(4) Sleeve slips over the shaft of the nail and has both a key to prevent rotation and a resister to give friction to the gliding motion.

(5) The assembled nail can extend to 6½ inches and shortened to 4½ inches.

(6) The intracapsular plate accepts 2 screws It is notched on either side to accept the driver (not shown on the plate).

(7) The intertrochanteric plate has 4 holes (the *slotted* plate has been discontinued). It is 4 inches long. It is clipped onto the butt of the sleeve and is not held by any bolt.

(8) The drills are $\frac{7}{64}$-inch in diameter and long enough ...

cannulated for a $\frac{7}{64}$-inch drill guide and are ½ inch in diameter.

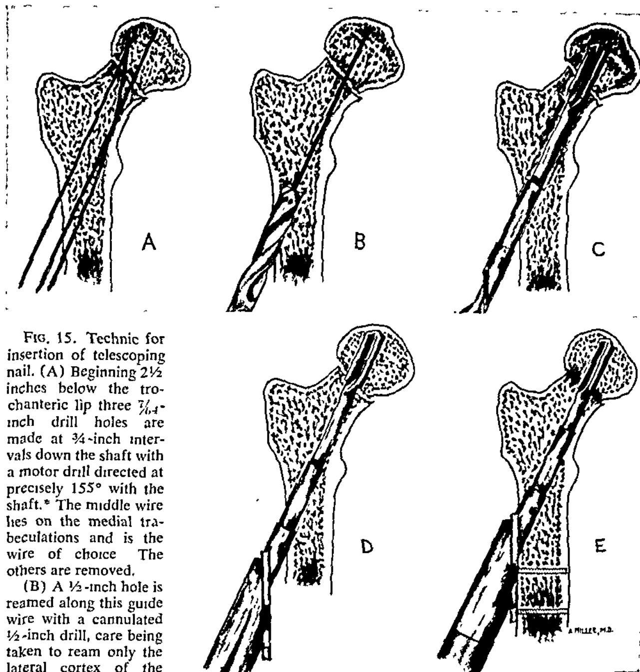


FIG. 15. Technic for insertion of telescoping nail. (A) Beginning 2½ inches below the trochanteric lip three 7/64-inch drill holes are made at ¾-inch intervals down the shaft with a motor drill directed at precisely 155° with the shaft.* The middle wire lies on the medial trabeculations and is the wire of choice. The others are removed.

(B) A ½-inch hole is reamed along this guide wire with a cannulated ½-inch drill, care being taken to ream only the lateral cortex of the femur.

(C) Then the inserter is attached to the nail-barrel assembly, the nail is extended to its full 6 inches and inserted along the guide wire the calculated depth. Less than an inch of the barrel will remain protruding from the lateral cortex.

(D) The 2-inch plate is clipped onto the distal end of the barrel, and with the impacter the whole assembly is pushed against the shaft. Two screws are inserted.

(E) Finally, with all traction removed from both legs, the distal fragment is impacted firmly against the head, with the impacter gaining purchase on the plate, which is held firmly to the distal fragment.

* See paragraph 7, page 246.

fragment. This accounts for three of six failures in the sliding-nail series. Therefore, patients are prohibited from crossing the affected leg. Sagittal stress, applied when the weight of the leg is lifted by its own muscles against gravity in either flexion or extension, produces a powerful angular stress on the fracture site proportionate to the weight of the extremity. Therefore, they are taught to lift the affected leg with the

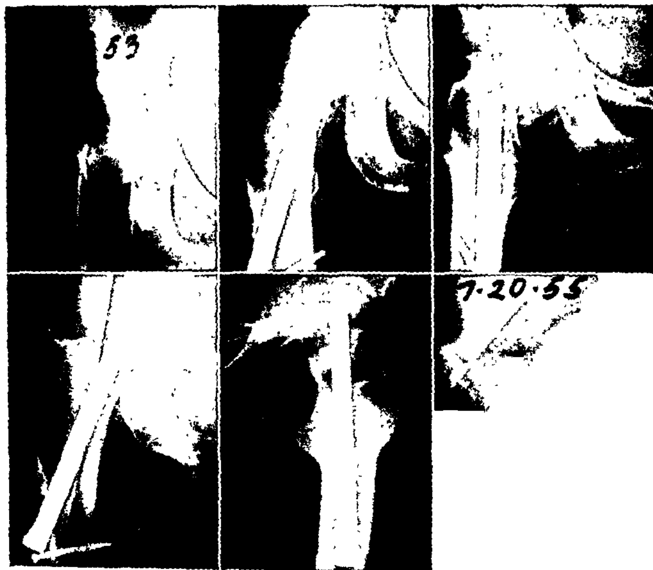


FIG. 16. A 56-year-old female alcoholic with a fracture-shaft angle of 45°. A flanged nail was inserted at 155° and a screw in the shaft to act as a buttress. She walked consistently against advice after hospital discharge. The nail backed out and nonunion resulted. She has a severe limp and uses crutches. The hip is painful. A sliding nail would have permitted impaction of the fragments at operation and might have prevented the subsequent displacement.

well leg in all positions when supine, and with the hands when sitting.

Elderly patients tolerate bed rest poorly. A week in bed weakens them greatly and complicates vastly the task of rehabilitation. Therefore, they are put in an antigravity position in the first 24 hours after operation and encouraged to use a walker as soon as practical. They are permitted to place the toes of the affected hip on the floor to aid in maintaining balance, but the knee must be kept flexed. If they walked regularly before the accident, they learn quickly to use the walker.

Full weight-bearing is assumed gradually, progress being made from a walker in elderly patients or from crutches in younger patients to a cane or a single crutch. Unsupported weight-bearing should be postponed until the proximal fragment has revascularized completely. Since, presumably, the degree of arthritis is proportionate to the degree of relative avascularity of the head and as yet there is no accurate means of

measuring the rate of revascularization, the dictum is followed that the younger the patient the more he has to lose should arthritis develop subsequently; therefore, the longer he should remain off weight-bearing. From 9 to 12 months is not excessive for younger patients. Blount's[2] admonition—"Don't throw away the cane" often has been repeated.

During convalescence, quadriceps resistance exercises, preferably against a weight or a scale—are prescribed. Finally, abductor resistance exercises are given the younger patients to obliterate any residual lurch. Some support is maintained in the contralateral hand until the limp is no longer present.

Discussion

The inability of many elderly patients to avoid weight-bearing consistently without constant supervision, which in low-income groups is prohibitive, has served as a stimulus for this presentation. Though others did not duplicate his results with this method, Whitman, through cast fixation alone, immobilized this fracture successfully in 89.2 per cent of 33 cases. Internal fixation has reduced morbidity and mortality, but it has not reduced consistently the rate of pseudarthrosis which still results often in from 10 to 30 per cent of the patients *This is unsatisfactory, since we are dealing with a simple fracture which, like all other fractures, will heal if it is reduced and immobilized adequately until healing ensues.* Some of us, as bone healing specialists, recently have attempted to avoid this onus by prosthetic replacement of the freshly fractured femur. However, when the smoke cleared, we discovered that, even in the otherwise well octogenarian with a life expectancy of only 10 years, the manmade appliance compared unfavorably with the healed fracture.

Faced, therefore, with the problem of obtaining healing in every ... , it is not enough to reduce a ... ...lly and then so immobilize it that inadvertent, intermittent weight-bearing (so common in the forgetful geriatric) results in motion at the fracture site by producing a shearing stress. Figure 15 shows a fracture reduced adequately and held with a rigid nail. An alcoholic, this 56-year-old woman walked intermittently without any support soon after discharge from the hospital. The nail inserted at 155° in the weight-bearing axis resisted such treatment until absorption of the neck allowed the nail to be extruded even over the resistance of a screw placed in the femur as a buttress. Nonunion developed. Similarly, in an 82-year-old woman (Fig. 17), the original fracture healed successfully, but avascular necrosis ensued, and she refused to abstain from weight-bearing for a prolonged period. A second fracture through the necrotic head resulted, the nail was displaced, and a nonunion followed. Another 82-year-old woman, equally recalcitrant, refused to use any support 1 month after operation. However, her fracture had been held with a sliding nail (Fig. 18). There was progressive absorption of both head and neck, avascular necrosis was present, the nail collapsed to its full extent but continued to give sufficient support to permit union to result. Though functionally the result was poor, the fracture healed.

The weight-bearing axis of every normally shaped femur passes along the medial trabeculations which measure approximately 155° with the femoral shaft. It follows then that to eliminate shear on it, the appliance should be introduced at 155° and the fracture line placed perpendicular to these trabeculations. The valgus position of the proximal fragment approaches this ideal, and, when impacted in this position, resumption of shearing stress at the fracture site is prevented (Fig 12). An anatomic reduction in the anteroposterior view is undesirable, no[illegible] because it is less stable but also [illegible] nail inserted at 155° then will [illegible] the lateral weight-bearing [illegible] ...oximal fragment (Fig. 4).



Fig. 17. An 82-year-old female senile dementia with a fracture-shaft angle of 35°. On 1-15-53 there was evidence of bony union, but the proximal fragment was avascular. On 8-8-53 a new fracture was demonstrated at the junction of the avascular portion, and the nail had backed out. She had fallen recently. She walked consistently against advice.

The fragments can be impacted with considerable force at the completion of the procedure. This simple step provides both adequate immobilization and adequate apposition of the fragments (Fig. 19). If the fragments are in close apposition, further impaction such as provided by weight-bearing is contraindicated. Eggers *et al.* demonstrated clearly that excess pressure resulted in marginal necrosis and delayed union. However, inadvertent or injudicious weight-bearing on a fracture held in valgus by a sliding nail will not result in a change of alignment. Similar weight-bearing on a fracture held in anatomic position by a nailplate at 135° to 140° results in a shearing stress equaling 10 to 30 per cent of the body weight applied to the fixation appliance and the fracture site. However, if this position of the nailplate is combined with a subtrochanteric osteotomy, which brings the fracture line perpendicular to the weight-bearing vector, a stable arrangement is constructed. In this series, however, it has been possible

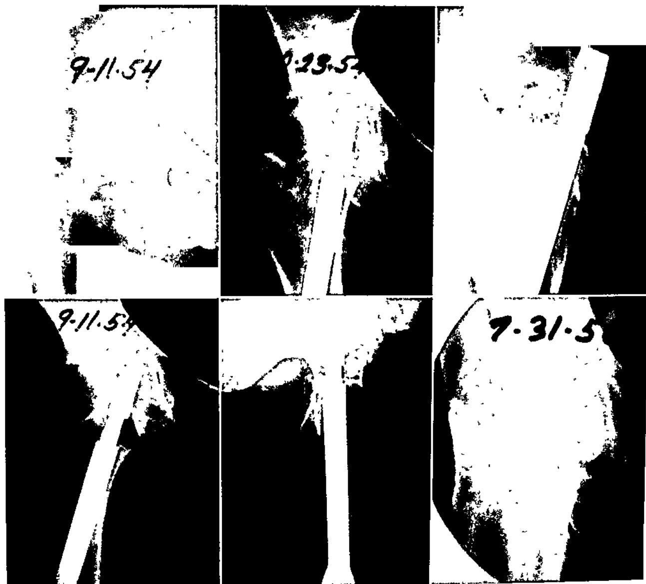


Fig. 18. An 82-year-old female with a fracture-shaft of 40°. Valgus position and internal rotation are adequate. Two weeks after operation she began full weight-bearing against advice. Progressive neck shortening is shown by the telescoping of the nail, but the nail did not penetrate the acetabulum. Avascular necrosis is obvious 7 months postoperatively, but union resulted. She has a moderate limp, restriction of motion and mild pain The nail has been removed to encourage revascularization.

in each case to manipulate the proximal fragment into sufficient valgus to make such an osteotomy unnecessary (Fig 11).

As discussed above, each of the six failures in the sliding-nail series could be explained adequately and thus repetition prevented Only three of the six failures in the rigid-nail group could be explained adequately. In the other three patients, no criticism could be made of the technic using the rigid appliance, so that the author had the uncomfortable feeling that in a certain percentage repetition of these failures seemed to be inevitable. Therefore, any method that results in union when all the prerequisites are met provides a real sense of security. If in any detail the technic has been faulty, then steps can be taken in time to prevent a calamity.

The use of the sliding nailplate offers several minor mechanical advantages. A single nail size is required for any patient. It has



FIG. 19. A 46-year-old female with a fracture-shaft angle of 25°. Overcorrection of the proximal fragment into valgus was not obtained, but at operation the distal fragment was impacted into the proximal fragment. Healing progressed normally, but due to her youth full weight-bearing was postponed 9 months, when a cane was provided for an additional 6 months.

been used for both intracapsular and intertrochanteric fractures, but its use in the latter provides no mechanical advantage over other appliances and has not been discussed in this chapter. The plate clips easily into place and requires no bolt fixation, thus avoiding any lateral projection which adds to patient discomfort when lying on the affected side. The detachable plate permits the use of a minimal length incision; it also can be converted into a drill guide by reversing its position on the barrel.

CONCLUSIONS

1. A comparative analysis of 21 intracapsular fractures held with a rigid-nail fixation and resulting in a 71 per cent bony union rate is made with 57 intracapsular fractures held with a sliding type of fixation and resulting in a 91 per cent bony union rate.

2. A new appliance and the method of inserting it are reported.

3. Finally, it is believed that nonunion of the uncomplicated intracapsular fracture

of the femur is preventable routinely; that union of this fracture, like all others, responds to the accepted principles of fracture healing and that when fixed in valgus by an adjustable length appliance the fracture becomes self-impacting and inadvertent or occasional full weight-bearing against instructions will not alter the normal course of bone healing. Hence the term *functional fixation*.

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Fixation Functional de Fracturas Intracapsular del Femore

Summario in Interlingua

Fracturas intracapsular del femore non differe ab altere fracturas quanto al facto que illos se resana uniformemente providite que le principios fundamental del resanation de fracturas es applicate. Nonobstante, il es ver que le application de ille principios—effectuation adequate de reduction, de apposition, e de immobilisation—es plus difficile in le caso de fractura intracapsular del femore.

Es discutite le bases rational pro le practica routinari de placiar le fragmento proximal in valgo, de impactionar le fragmentos in le plano sagittal, de fixar le fragmentos per medio de un clavo con placa glissante a un angulo de 155 grados con le diaphyse femoral, e de impactionar le fragmentos firmemente super le tabula de operation.

Es comparate duo series de casos, le prime tractate per fixation del fractura con un clavo rigide, le secunde con fixation per clavos a placa glissante. In ambe series le fragmento proximal esseva uniformement placiate in valgo, e le clavo esseva placiate a un angulo de 155 grados al longo del calcar femoral, sed in le gruppo a clavo rigide il non esseva possibile obtener impaction al tempore del operation. Le gruppo a clavo rigide, includente 25 casos consecutive, resultava in non-union in 25 pro cento del casos. Le gruppo a clavo con placa glissante continua augmentar se. Le prime 30 casos in illo resultava in nulle non-union. Iste contrasto inter le duo series es analysate. Le importante differentia inter illos es le non-effectuation del impaction in le gruppo a clavo rigide, proque in consequentia de illo il occurreva necessarimente un violation de duo del principios fundamental de resanation de fracturas—le principio del apposition adequate e illo del immobilisation adequate.

Le clavo a placa glissante e le technica de su uso es describite.

Le periodos post-operatori es non ancora satis extense pro permitter un evaluation definitive del incidentia de necrosis avascular. Usque al tempore presente, ille incidentia ha retrogradite considerabilemente in comparation con le gruppo a clavo rigide.

Le substitution de protheses es disrecommendate (con pauc exceptiones) proque su resultatos a longe vista non es comparabile con illos de fracturas resanate. Es describite, como alternativa, un methodo de fixation que premitte le continue auto-impaction del fragmentos per le action muscular in le axe del portage de pesos, e si le patiente porta pesos—accidental—o mesmo intentionalmente in violation del instructiones—il resulta nulle alteration in le curso normal del resanation. Isto justifica le termino "fixation functional."

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Supracondylar Fractures of the Femur*

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Supracondylar fractures of the femur are a definite challenge. Good reduction and adequate and firm internal fixation are essential if knee motion is to be preserved. Too often, marked limitation of motion of the knee joint results from these fractures. Contractures may be due to adhesions within or about the knee or adhesions and scarring between the quadriceps and the fracture site, the result being a diminished range of knee motion. Good bony union after an excellent reduction of the fracture may be obtained, but disability due to marked stiffness of the knee may well be the end-result.

Prolonged immobilization in plaster casts tends to loss of knee motion, which is very difficult to overcome.

The purpose of the authors in this chapter is to present a method of treatment of supracondylar fractures of the femur which provides anatomic reduction of the fracture and stable fixation without external support, thus allowing early mobilization of the knee and the patient as a whole.

In November, 1946, before the Interurban Orthopaedic Society in Durham, N. C., Dr. Hugh A. Thompson, of Raleigh, N. C., presented a case that he had treated with a blade-plate in the fall of 1943.

Dr. Alfons R. Altenberg and Dr. Richard L. Shorkey reported in the *Journal of Bone and Joint Surgery* of April, 1949, 3 cases that they had treated with the blade-plate method.

On February 1, 1950, Dr. Eugene L. Jewett utilized his hip nail for fixation of an open supracondylar fracture of the femur by bending the plate of the nail to make it conform to the contour of the lower end of the femur. Later he designed a nail for this purpose.

Since 1950 we have treated 36 cases of supracondylar fractures of the femur by open reduction of the fracture and internal fixation with the Jewett supracondylar nail. The 3-flange nail has been increased in width to ¼ inch to afford firmer fixation of the condyles of the femur. Since this type of fixation has proved to be adequate for fractures of the upper end of the femur, this nail of a similar design affords firm fixation for lower femoral fractures.

Knee motion is started the day after surgery. Good bony union of the fracture has occurred in each of our cases, and the range of knee motion has been most gratifying.

The fracture site is exposed through a lateral approach. The rectus femoris muscle is retracted medially, and the vastus lateralis is retracted laterally and posteriorly. The vastus intermedius is divided along the course of its fibers. Thus the fracture is adequately exposed. Should an intercondylar fracture also be present, the incision is extended to open the knee joint in order to align anatomically the articular surfaces of the femur. This was necessary in nineteen of our cases. First the intercondylar fracture is reduced and held with a bone-holding

[illegible] Joint

[illegible] Fla.

clamp while a transfixion screw or bolt is placed across the condyles. Then a guide wire is drilled transversely across the condyles. If there is any doubt as to the position of this guide wire, a roentgenogram should be taken. Next, a bur reamer threaded over the wire is used to open the lateral cortex, and the supracondylar nail is threaded over the guide wire and driven across the condyles so that the tip of the nail just emerges through the cortex on the medial side of the femur. Traction is applied by means of the supracondylar nail, a Kirschner bow being used on the guide wire if necessary. By this traction the fracture is reduced anatomically, and the plate portion of the nail is fixed to the shaft of the femur with screws of appropriate lengths. When practical, iliac bone chips then are packed around the fracture site.

The closure of the operative wound in layers follows the routine technic. A sterile dressing is applied over the operative incision, and an ace bandage is applied from the toes to the high thigh. No form of external immobilization or fixation is used.

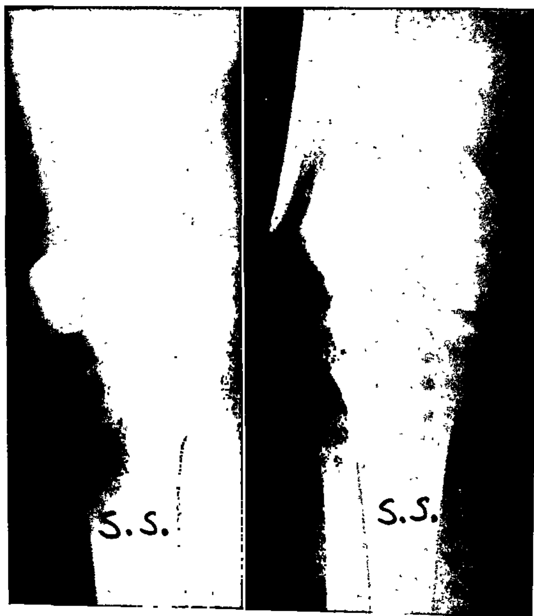


FIG. 1. S. S, Negress, age 46. Roentgenograms made on admission of comminuted supracondylar fracture of the left femur.

Early knee motion is of prime importance during the postoperative care of these patients. *Passive knee motion is started the day* after surgery and is repeated 2 or 3 times daily afterward. Quadriceps setting exercises and some active knee motion are started as soon as tolerated by the patient. The patient is allowed up on crutches or in a walker between the tenth and the fourteenth postoperative days. *Full weight-bearing is not* permitted until the patient has good bony union of the fracture, demonstrated by roentgenographic examination.

An analysis of the 36 cases we are re-

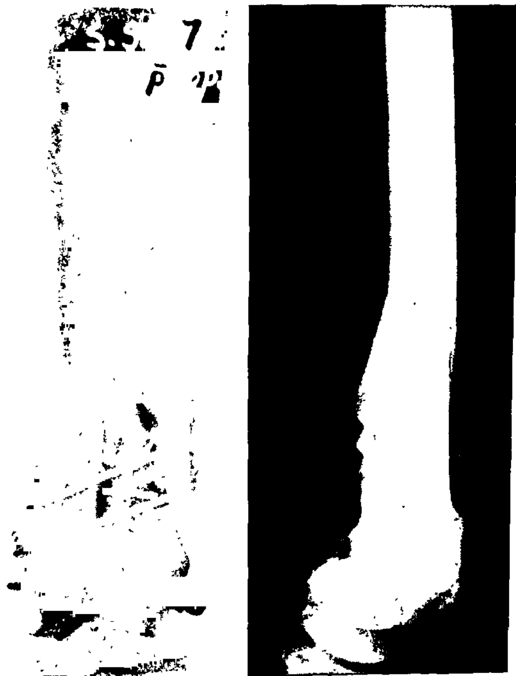


FIG. 2. Same patient as in Figure 1 showing fixation with nail and screws 7 months postoperatively.

porting reveals that the ages of the patients range from 15 to 87 years. The average age was 55 years.

Seventeen of these injuries were received in automobile or motor-scooter accidents. Ten were the results of falls in the home. Three occurred in falls out of bed or a wheel chair. Three were industrial injuries, and 2 were the result of gunshot wounds of the thigh. One case was that of nonunion of a supracondylar fracture.

A case of malunited supracondylar fracture, 2 years after the initial injury, is included in this report. An osteotomy of the femur was done in the supracondylar region, and the above-mentioned method of treatment was instituted.

Nineteen of these cases were intercondylar or T fractures. Seventeen involved only the shaft of the femur in the supracondylar region. A great majority of the fractures were comminuted.



FIG. 3. M. T., white female, age 54 Roentgenogram of comminuted supracondylar fracture of the right femur taken on admission.



FIG. 4. Same patient as in Figure 3 showing fixation with nail 15 months postoperatively.

Complications were encountered in 2 cases. In 1 case the nail broke after 6 months. In this case a supracondylar nail was reinserted. Iliac bone grafts were also used. Good bony union of the fracture resulted. There was 1 case of postoperative infection, which cleared up with antibiotic therapy.

With the exception of the case in which the nail broke, the average length of time for bony union was 5 months. In fourteen of the cases iliac bone was placed around the fracture primarily. The average hospital stay was 26 days. The range of motion of the knee in all 36 cases was good.

We feel that this method of treating

supracondylar fractures affords the greatest chance for a normal range of motion of the knee, a more perfect reduction of the fracture, a shorter period of morbidity, faster healing of the fracture and more comfort to the patient.

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FIG. 5. C. A., white male, age 50. Right femur.

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FIG. 6 Same patient as in Figure 5 immediately after operation

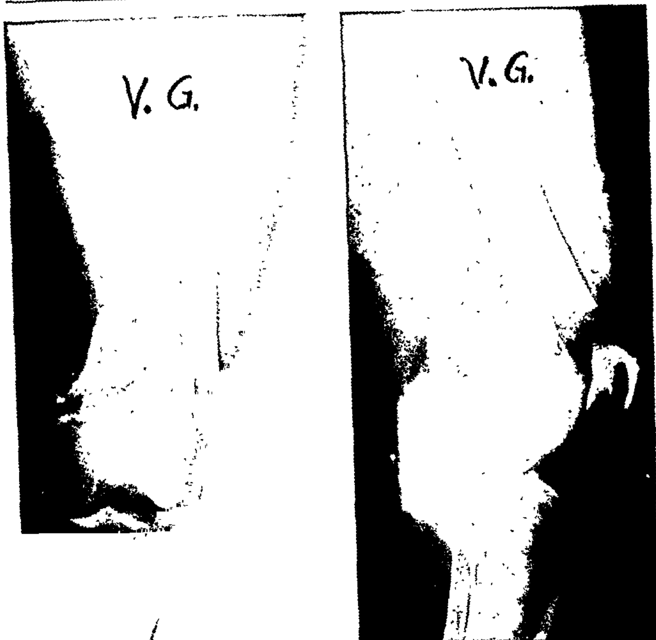


FIG 7. V. G., Negress, age 32, showing gunshot wound which produced a severely comminuted supracondylar fracture.

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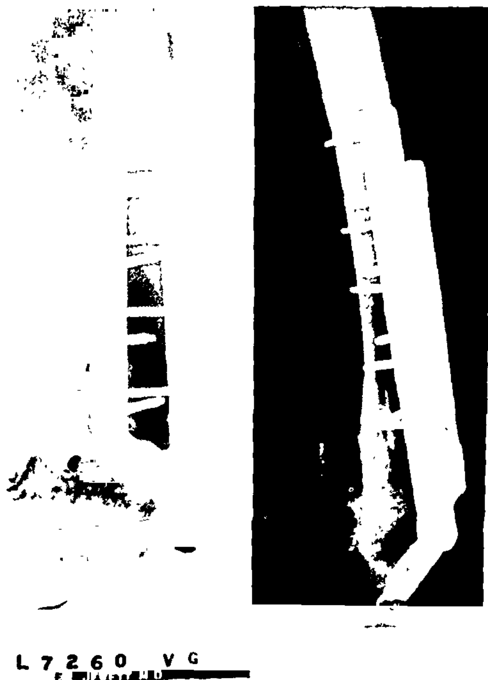


FIG 8 Same patient as in Figure 7 showing fixation with dual plate nail 15 months postoperatively.

Fracturas Supracondylar del Femore

Summario in Interlingua

Le limitation invalidante del motilitate in le articulation del genu, incontrate si frequentemente post fracturas supracondylar del femore que ha essite tractate per immobilisation in gypso, ha inducite nos a cercar melior methodos de tractamento pro iste typo de fractura.

Es presentate un revista de methodos non-immobilisatori introducite per alteres, con le objectivo de determinar le originator del methodo adoptate per le autores.

Trenta-sex fracturas esseva tractate per reduction apertee fixation interne per medio de un clavo con alas, formate de un sol pecia. Nulle fixation externe esseva applicate, e motion del genu esseva instituite post un breve intervallo. Un bon union de osso resultava in omne le trenta-sex casos. Le usual motilitate del genu que esseva obtenite amontava a 110 grados.

Es mentionate le complicationes incontrate, e duo casos con complicationes es reportate individualmente.

Dece-nove del trenta-sex fracturas supra-



Fig 9 R H, white male, age 15 Roentgenogram made on admission showing comminuted supracondylar fracture.



FIG 10. Same patient as in Figure 9 showing fixation with nail 3 months postoperatively

condylar del femore esseva fracturas intercondylar (in forma de T). Le grande majoritate esseva comminutive. Graffos de osso iliac esseva placiate circa le sito del fractura in dece-quatro casos. Le tempore medie del union de osso esseva cinque menses.

In nostre experientia, iste methodo de tractar fracturas supracondylar offere le melior prospecto pro le restitution de un motilitate normal del genu. Illo assecura un plus perfecte reduction del fractura. Le periodo de morbiditate es abbreviate, e le curation del fractura es accelerate. In comparation con altere methodos, le hic recommendate modo de tractamento resulta in minus dolor e disconforto pro le patiente.

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Lumbosacral Fusion: The Mortised Transfacet Method by Use of the Vibrating Electric Saw for Circular Bone Blocks*

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Since 1945, the mortised transfacet bone-block technic for fusion of the lumbosacral region of the spine has been used routinely at the McBride Clinic in more than 1,000 cases. Consistently good clinical results have satisfied those whose activities place great demands on their backs. In our community, ranchmen with vast acreages expect to return to their tractors for long, continuous hours. Laborers, such as oil-field drillers and tool pushers, must be "supermen" to hold their jobs.

One of the reasons that this operation has been satisfactory is that the technic renders dependable assurance of fusion with essentially little more temporary disability than that induced by solely removing a disk. The firmly impacted bone blocks provide immediate immobilization of the involved vertebrae, permitting the patient to get onto his feet as early as the third postoperative day With a supporting plaster jacket he can be active in 3 weeks. Essentially, this technic has remained unchanged over a 12-year period.

The maxim upon which this technic rests is that "a successful fusion depends on where and how the bone graft is implanted, not upon the amount of bone utilized." When the vibrating electric saw became equipped with a trephine cutting tool for making circular bone plugs, McKeever[4] called our attention to the feasibility of making transfacet blocks round instead of rectangular, as originally recommended. It was readily conceived that the use of the circular tool would provide more mechanical perfection. However, it must be pointed out that there are situations in which the rectangular block still is preferable. The circular block may be used when the transverse bone area of the facets is great enough to leave a complete, or almost complete, circle of solid cancellous bone around the depth of the mortise. Nearly always, this situation may be found in the lumbosacral facets, inasmuch as they are in the flattened position of the frontal plane. The sagittal plane of the facets between L 4 and 5 often fail to provide a wide enough cutting area to leave substantial borders for firm support of the impacted circular block. Especially is this true where foraminotomy or more extensive laminectomy is necessary. Here it may re-

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quire considerable ingenuity and use of hand tools to make a rectangular mortise that will transfix the facets substantially.

The mechanics involved in fusion of joints in general have been elaborated upon extensively, but nothing will susbtitute for sound mechanical principles in fusion of the low lumbar region. A chain is no stronger than its weakest link, but a small column may support the corner of a great building. A facet bone graft across a joint will oppose motion to no greater degree than the weakest point which forms the bony bridge. Accuracy of edge-to-edge contact and firm compression of the embedded bone graft is the best assurance of union. It must be realized that the edges of the denuded vertebral facets cannot be compressed together, as is usually possible when bone grafts for fusion are embedded across other joints. After thorough removal of the facet articular cartilage, the remaining space cannot be closed because the vertebral bodies cannot be shifted. Since inadequate immobilization is the principal source of failure in any bone-graft operation, the laminae must be widely distracted when the graft is implanted so that they will react with firm compression when the spreading instrument is removed.

The mechanical advantages of the circular graft are:

1. Mechanically, the graft implant is perfect.

2. When distraction is released, compression of the graft between the laminae is effective throughout the entire circumference of the graft.

3. The firmly impacted round graft provides accurate approximation of the cancellous edges of the graft and its host.

4. The round block will not cut or work into the edges of its host.

5. Revascularization is favored by the similarity of the spongy cancellous bone graft and its host when the spinous processes or iliac bone is used.

6. A small graft will revascularize and unite quicker than a large one.

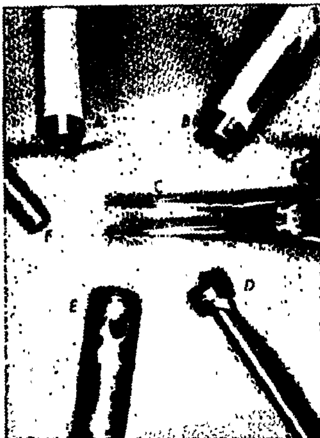


Fig. 1. (A & B) Circular trephine, No. 7 and No. 8. (C) Laminae retractors. (D) Forstner bit. (E) Margo circular cutting punch. (F) Blunt punch.

7. In the event of reoperation, this operation permits re-exposure of the neural canal without disturbing the fusion.

FUSION IN DISK SURGERY

Comparative simplicity favors this facet method for fusion in herniated-disk surgery. It is recognized universally that the herniated-disk syndrome is the ultimate result of structural deficiency. Degenerative depreciation of the articular integrity occurs gradually as the result of abnormal mechanical stresses. More often, there is a basic deviation from normal formation, or alignment, through anatomic anomaly or asymmetry. Back disability was attributed to such mechanical disturbances and treated successfully by fusion long before the discovery of the disk syndrome. Removal of the offending disk protrusion alone is not likely to re-

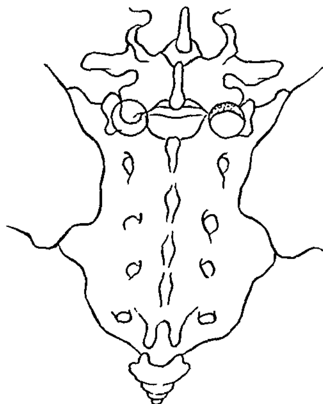


FIG. 2. Posterior view of trephined excavation across the lumbosacral facets, *reamed to a depth of 3/8 inch to 1/2 inch.*

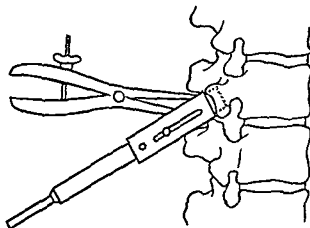


FIG. 3. Lateral view of trephine directed across the facets toward the pedicle while the laminae are distracted forcibly.

lieve the residual effects of progressive arthritic erosion and ligamentous weakness. How can such facts be ignored so commonly? Is there any good reason why the operation for herniated disk should not include complete exposure and inspection for abnormalities, such as mechanical erosion of the facets, malformations or anatomic misalignment of the posterior structures?

TECHNIC OF USING THE CIRCULAR SAW FOR BONE BLOCKS

The equipment of the Stryker vibrating bone saw provides trephine cutting tools in various sizes. Generally, the No. 7 size is used for making the mortise in the distracted facets. The No. 8 size is used to cut the bone block to be impacted. The bone blocks may be made from the spinous processes or taken from the ilium. When the spinous processes are used, the bone must be held with a viselike grip in a bone forceps otherwise the vibrating blade will not cut. Circular punches of various sizes which are quicker and more expedient to use for cutting the spinous processes have been devised by Elias Margo.[5] To cut the mortise the laminae are distracted forcibly. The *circular blade is placed on the facets* at a 20° angle downward and outward, in line with the pedicle below and not directly toward the foramen. The nerve will not be damaged by the saw if it is directed properly and if correct depth adjustment has been made. The object should be to cover as much of the articular portion as possible and leave a good substantial circular bony rim. Water is dripped adequately on the saw as it cuts to prevent burning. The circular holes are reamed out with a Forstner bit and hand drill to leave a smooth cancellous base. The bit and drill may be obtained from any good hardware store in the exact sizes needed. The bone grafts are impacted firmly in their beds, and the distractors are removed. Bone chips, Hibbs' style, are turned down from the laminae above and below to cover the edges of the implants.

TECHNIC IN GENERAL

Incision. Usually, the area should be exposed thoroughly to provide inspection of the laminae and the articular facets of

L 4-5 and S-1. The incision should start at the upper margin of the spinous process of L-3 and extend in the mid-line straight downward to the spinous processes of S-2 and 3. The soft tissues are separated from their attachments to the spinous processes by subperiosteal elevation, as originally described by Hibbs, alternately packing the side opposite to the use of the elevator. All ligamentous attachments are thoroughly removed subperiosteally from the laminae out to the lateral border of the articular facets. Electrocoagulation is used for oozing vessels, and adequate retraction is obtained by heavy spreading spine retractors. The spinous processes of L 4 and 5 and S-1 are excised deeply at their base and passed to an assistant, who denudes them thoroughly of all soft tissues so that they can be used later for bone-block plugs. Before removing the interlaminal fat pad, the small artery entering it should be clamped and electrocoagulated. This provides definite exposure of the facets with a dry field. The dura is exposed by starting with a linear mid-line incision in the ligamentum flavum, into which a smooth blunt blade is inserted to retract and protect the dura while the ligamentous incision is continued. Clear visualization of the nerve root is made possible by adequate removal of portions of the lamina above and below with a Kerrison bone-cutting forceps. The dura is pressed cautiously toward the mid-line, and the nerve is hooked with a nerve retractor If due care is used, the troublesome veins can be pressed to one side with wet cottonoid pledgets. If the veins are broken and the bleeding is profuse, the cottonoid pledgets should be packed firmly above and below the nerve roots and the veins electrocoagulated cautiously. Then the protruding disk is removed, together with all remaining nucleus pulposus that can be grasped with pituitary rongeurs inserted in the intervertebral space. Fusion of the facets is described in the previous paragraphs.

REMOVAL OF BONE BLOCKS FROM ILIUM

McKeever utilized the entire thickness of the ilium for his larger interspinous bone blocks by excising a large portion of the anterior ilium. For the facet bone-block operation it is preferred to create as little traumatic disturbance to the ilium as possible. The blocks may be taken from the region of the posterior spine without a second incision. Remove the spinal retractors from the incision and extend the exposure subfascially to the prominence of the posterior iliac spine. With rather firm retraction the circular saw blade can be pressed perpendicularly, or horizontally, against the posterosuperior spine area of the ilium, near its upper edge, to cut into it for about ½ inch. From 2 to 4 cuts are made. A thin osteotome is directed into the base of the saw cut, and with a little leverage the block pops out. When a second incision is used, the procedure is easier, and the blocks may be removed from a thinner area of the ilium, but a persistently painful area may result.

DISCUSSION

The senior author first published the technic for the mortised transfacet graft operation for spinal fusion in 1949.[1-3] Despite its theoretic advantages, the circular facet fusion could not be recommended without adequate clinical proof of effectiveness. The years 1954, 1955 and 1956 were selected as being representative years in which both the circular and the rectangular facet grafts were used in this clinic. All records and roentgenograms of spinal fusions performed during those years were reviewed. As many patients as possible were contacted to determine the final result.

Biplanar roentgenograms have been a routine part of the postoperative care at this clinic following all spinal fusions. These are made 4 to 6 months after operation. All roentgenograms were reviewed carefully and all those that did not superimpose perfectly, either in the anteroposterior or the lateral

TABLE 1. COMBINED LUMBOSACRAL AND L 4-5

			Total No. of Cases	Percentage
Operated on			82	
Inadequate follow-up			5	
Cases studied			77	
Rectangular method			27	35
Circular method			49	64
Interbody method			1	1
Roentgenographic evidence of pseudarthrosis			28	36
Rectangular	10	37%		
Circular	17	35%		
Interbody	1	100%		
Roentgenographic evidence of fusion			49	64
Rectangular	13	63%		
Circular	36	65%		
Roentgenographic evidence of pseudarthrosis at:				
		% of Cases (28) with Pseudarthrosis		
Both levels	9	32%		
L 4-5	14	50%		
L S	5	18%		
Good clinical results			70	91
Fair clinical results			5	6
Poor clinical results			2	3
Private patients			49	
Good results	46	94%		
Fair results	3	6%		
Industrial patients			28	
Good results	24	66%		
Fair results	2	7%		
Poor results	2	7%		

views, were considered to show pseudarthrosis. Biplanar roentgenograms are our best method of determining fusion in vertebrae which have not been subjected to massive grafting. However, there is still a great deal of inaccuracy in the usual biplanar roentgenograms. The slightest rotation of the body position will prevent accurate superimposition of vertebral shadows. Also, in the case of fusion of the facets only, it is *conceded generally that there will be a very* slight spring between the vertebrae for 4 to 6 months which may show minimal motion in a biplanar film and yet eventually firm fusion will occur. Despite its many drawbacks, it is still the most satisfactory method of establishing proof of bony union.

The lumbosacral fusion is used most commonly following disk surgery, for degenerative joint changes and for painful backs from so-called hypermobility. A review of the entire series of charts—fusion of only the lumbosacral, fusion of L 4 and 5 and the sacrum, or fusion of L 4 and 5 alone without fusion to the sacrum—shows a very *marked similarity in the results from the* rectangular and the circular grafts. Results were tabulated as "good" when the patient had no complaints and felt himself that the operation had been entirely successful and

TABLE 2. LUMBOSACRAL

			TOTAL NO. OF CASES	PERCENTAGE
Operated on			265	
Inadequate follow-up			12	
Cases studied			253	
Rectangular method			62	25
Circular method			189	74
Interbody method			2	1
Roentgenographic evidence of pseudarthrosis			25	10
Rectangular	6	10%		
Circular	17	9%		
Interbody	2	100%		
Roentgenographic evidence of fusion			228	90
Rectangular	56	90%		
Circular	172	91%		
Good clinical results			235	93
Fair clinical results			10	4
Poor clinical results			8	3
Private patients			175	
Good results	163	93%		
Fair results	7	4%		
Poor results	5	3%		
Industrial patients			78	
Good results	72	92%		
Fair results	3	4%		
Poor results	3	4%		

as "fair" when the patient had not been relieved completely of all pain. "Poor" is self-explanatory.

The following tables show a detailed breakdown of the findings in 377 patients who underwent operation during the years described above. In Table 1, the combined fusion of L 4 and 5 and S-1 was studied in 77 cases The rectangular and the circular grafts showed questionable pseudarthrosis in 37 per cent and 35 per cent of cases, respectively. However, good and fair clinical healing was obtained in 97 per cent of the total cases. Private patients were rated as good in 94 per cent, and industrial patients were close, with 86 per cent being good.

The most common level of fusion is the lumbosacral joint. It is seen in Table 2 that 90 to 91 per cent of rectangular or circular grafts united The final result shows 97 per cent to be good or fair. Essentially there was no difference between private and industrial patients. Table 3 was included for completeness. It outlines the results for fusion only between L 4 and 5, which is a more rare procedure. As might be anticipated, a rather low percentage of fusions was seen in biplanar roentgenograms; however, the clinical results were excellent.

SUMMARY

The technic of the circular transfacet mortised fusion has been described. The percentage of fusions between L 4 and 5, between L 4 and 5 and the sacrum, and in the lumbosacral joint has proved to be comparable with the previously reported results of rectangular grafts. Satisfactory clinical results of facet graft fusions have always exceeded the number of cases showing solid bony union. This would indicate that the separation of the laminae and locking of the

TABLE 3. L 4 AND 5

			Total No. of Cases	Percentage
Operated on			30	
Inadequate follow-up			1	
Cases studied			29	
Rectangular method			7	24
Circular method			22	76
Roentgenographic evidence of pseudarthrosis			12	41
Rectangular	4	57%		
Circular	8	36%		
Roentgenographic evidence of fusion			17	59
Rectangular	3	43%		
Circular	14	64%		
Good clinical results			28	
Poor clinical results			1	
Private patients			23	
Good results	22			
Poor results	1			
Industrial patients			6	
Good results	6			
Poor results	0			

grafts in itself is of real value, even if they do not become completely solid. It was also found that clinical and roentgenographic results in private and industrial patients were essentially the same.

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Fusion Lumbosacral: Methodo a Mortaza Transfaciettal, con le Serra Electro-Vibratori pro Blocos de Osso Circular

Summario in Interlingua

Le technica a blocos de osso in mortaza transfaciettal pro fusiones in le region lumbosacral del spina dorsal ha essite in uso routinari al Clinica McBride depost 1945, uniformemente con bon resultatos clinic. Le advento del vibrante serra-trepano ha rendite possibile un multo plus grande precision que illo possibile con utensiles manual in le excision del graffos ossee e del mortazas transfaciettal Le blocos rectangular que esseva originalmente in uso continua esser preferibile in casos exceptional in que le *faciettas non es sufficientemente large pro* provider un circumferentia circummortazal de osso solide

Le avantages mechanic del graffo circular es:

1 Perfection mechanic del graffo a implantar.

2. Le compression del graffo resultante

del relaxation del distraction laminar es efficace in omne partes del circumferentia del mortaza.

3. Le firmamente impactionate graffo circular provide un accurate *approximation* inter le margines cancellose del graffo e del mortaza.

4. Blocos circular non se seca o pressa a in le margines del mortaza.

5. Revascularisation es favorate per le similitude del spongiose graffo de osso cancellose e su recipiente quando processors spinose o osso iliac es usate.

6. Un micre graffo se revascularisa e se reuni plus rapidemente que un graffo plus grande.

7. In caso de re-operation, le area graffate non obstrue le re-exposition del canal neural.

Technica

Le vibrante serra ossal de Stryker provide pecias de incision in varie dimensiones. Usualmente numero 7 es usate pro facer le mortaza e numero 8 pro facer le bloco de osso a impactionar. Le processos spinose, excidite a lor base al tempore del exposition, pote esser usate pro le blocos de osso, sed istos pote etiam esser prendite ab le ilium. Le mortaza circular que es effectuate per le trepano vibrante es finite manualmente con un trepano typo Foerstner pro obtener un lisie base cancellose. Le trepano Foerstner pote esser obtenite ab un quincalieria.

Le laminas es extendite con fortia durante le effectuation del mortaza de maniera que le *bloco circular* es *rigidemente comprimite* in su sito quando le distraction es relaxate.

Resultatos

In 76 casos de fusion combinate de L-4/5 e S-1, roentgenogrammas biplan indicava que le fusion esseva questionabile in 36 pro cento del casos, sed bon resultatos clinic esseva establite in 94 pro cento.

Un comparation del technica a blocos rectangular con illo a blocos circular monstrava practicamente nulle differentia in le resultatos final.

In 253 casos de fusion del articulation lumbo-sacral, effectuation del fusion esseva constatate in 80 pro cento del casos e bon resultatos clinic in 93 pro cento.

In fusion de solmente L-4/5 in 29 casos, questionabile soliditate del fusion esseva constatate per roentgenographia biplan in 41 pro cento del casos e bon resultatos clinic in 98 pro cento.

Viste le alte procentage de bon resultatos clinic, le conclusion pareva justificate que le test per roentgenographia biplan non es digne de confidentia como indicator de fusion solide.

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Fracture-Dislocation of the Radius and the Ulna at the Elbow Joint

Report of a Case Treated by Excisional Surgery and Temporary Transfixation of the Joint with a Kirschner Wire*

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Fracture-dislocation of the head of the radius and the ulna at the elbow joint without damage to the humerus is quite rare. The literature contains very little information on either the treatment or the end-results of this particular combination of injuries.[8,16,17,22,23] This case is of special interest because it presents the problem of treatment of two difficult fractures in a single joint.

CASE REPORT

A janitor, 55 years of age, had an epileptic seizure, fell from a stepladder while he was washing the ceiling and injured his left elbow. Upon regaining consciousness, he felt intense pain and limitation of motion in his left arm. After first aid at home, the arm was immobilized in a triangular bandage; gradually, the region of the elbow became increasingly swollen and there was complete loss of all joint motion when he arrived at the hospital.

Past History. The past history except for idiopathic epilepsy was noncontributory.

Physical Examination. The patient was a small, well-nourished, pale, asthenic man in acute distress. On admission, the entire left upper extremity was swollen and edematous. The skin over the dorsum of the left elbow was thin and shiny and infiltrated with extravasated blood. The three important bony landmarks—the two epicondyles and the olecranon process—were completely obscured by swelling, and there was a decreased carrying angle. There was a jog of extension and flexion of the elbow, but no rotation was possible. There was marked and diffuse tenderness about the elbow. The elbow was maintained at 90° flexion; in this position the olecranon process palpated through boggy, ecchymotic tissue, was displaced upward in the mid-line between the epicondyles. There were no signs of nerve or vascular injury.

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Laboratory and Roentgenographic Examinations. The complete blood count, urinalysis, serologic tests and electrocardiogram were within normal limits. Roentgenograms disclosed very extensive comminuted fractures of the olecranon process and the head and the neck of the radius (Fig. 1). The proximal portion of the olecranon process was displaced slightly posterior, disclosing a major fracture line extending around its base and around the distal third of the circumference of the greater sigmoid notch. There was also an incomplete, nondisplaced fracture through the base of the coronoid process. In addition, there was an oblique, irregular fracture line extending through the head and the neck of the radius. Anterior and distal to the neck of the radius, there was a triangular fragment of bone which appeared to be a portion of the radial head (Fig. 1, *right*).

TREATMENT

Conservative Treatment

The left upper extremity was suspended and elevated with skin traction, 6 pounds of weight being used. This reduced some of the swelling of the elbow and arm. After 2 days, roentgenograms revealed posterior subluxation of the elbow joint without improvement in the alignment of the fractures. The elbow was manipulated gently, the traction suspension was rearranged, and the weight was reduced to 3 pounds. In a state of confusion following an epileptic seizure, the patient misunderstood instructions, sat up in bed, and frequently disengaged himself from the apparatus. This resulted in a complete posterior dislocation of the forearm bones on the humerus.

Subsequently, two attempts at closed reduction under intravenous Demerol and in-

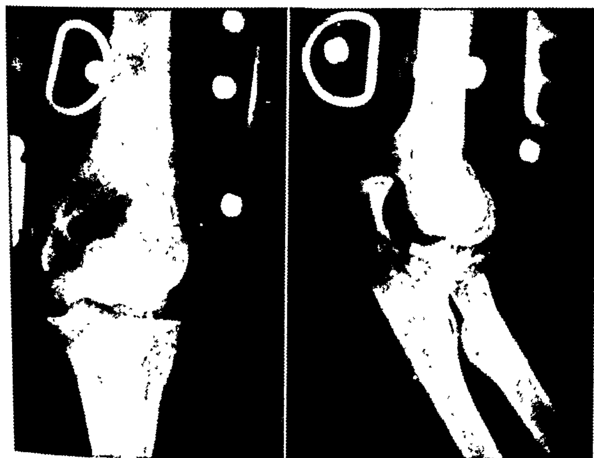


Fig. 1. (*Left*) Roentgenogram, anteroposterior view, showing a comminuted fracture of the head of the radius and the olecranon process. (*Right*) The same elbow, lateral view. Note dislocation of the elbow

halation Trilene anesthesia failed to reduce the dislocation. Then the arm was immobilized in a posterior splint for 2 weeks until the swelling was diminished in the soft parts around the elbow joint.

Surgical Treatment

On the seventeenth day after the injury, arthrotomy, with excision of the fragments of the radius and the ulna, was performed with intramedullary, transarticular fixation of the ulna to the humerus (Fig. 2). The joint was exposed through a Boyd posterolateral approach. There was a large partially organized blood clot inside the joint cavity and extending into the edematous subcutaneous tissues and hemorrhagic muscles. The triceps tendon was shredded and contused. There was extreme comminution of the radial head, as well as the entire proximal portion of the olecranon process. All fragments of the olecranon and the radius were removed, including the fragments that were displaced into the antecubital fossa. This left only a small area—approximately 1 cm —of the saddle of the olecranon on the medial side of the joint behind the coronoid process. It was impossible to hold the hu-



Fig 2 (*Left*) Roentgenogram, anteroposterior view, showing the elbow joint following excision of the olecranon and the head of the radius and internal fixation with a transarticular Kirschner wire incorporated in plaster. (*Right*) The same elbow, lateral view.

merus in place upon such a small remnant of the surface of the ulna. For this reason the upper end of the ulna was transfixed to the lower end of the humerus with a large Kirschner wire. A long-arm cast was applied with the wire incorporated into the plaster to maintain the elbow in a position of 135° of extension. It was impossible to reapproximate the damaged triceps tendon overlying the olecranon defect. A petrolatum gauze pack was inserted in the wound to fill the dead space, and the wound was closed loosely in a single layer.

The postoperative course was uneventful. On the fourth postoperative day a window was cut in the cast overlying the wound, and a portion of the pack was removed daily. The wound healed cleanly within 3 weeks. The Kirschner wire was removed, and the cast was incorporated in a Velpeau plaster splint for 2 months. On removal of the cast the patient's range of elbow motion was from 50° of flexion to 150° of extension with 45° of supination and 60° of pronation (Fig. 3). Subsequently hydrotherapy and graduated active motions were prescribed to the elbow. Six months following surgery the patient improved his range of motion to acquire an additional 10° of flexion and extension, 30° of supination, and 20° of pronation without pain. The patient felt that he had secured an excellent result, but he described a feeling of "uneasiness" in the elbow when, against medical advice, he attempted to lift more than 25 pounds with his left arm.



Fig. 3. (*Left*) Roentgenogram of the elbow, anteroposterior view, 2 months after excision of the head of the radius and the olecranon process (*Right*) The same elbow, lateral view. The triceps tendon was sutured to the capsular ligaments and the proximal end of the ulna at the point indicated by the arrow.



FIG. 4. (*Left*) Showing 65° of flexion of the forearm in the range of 105° of painless active motion possible 1 year after injury. (*Right*) Showing 170° of extension of the forearm in the range of 105° of painless active motion possible 1 year after injury.

END-RESULT

One year postoperatively the elbow range of motion had remained relatively constant; the patient attained 65° of flexion and 170° extension and good stability (Fig. 4). Roentgenograms at this time showed periarticular, heterotopic ossification. Neuromuscular function continued unimpaired, and there was no evidence of delayed ulnar neuralgia.

DISCUSSION

Five consultants who had considerable experience with injuries of the elbow joint suggested the following different forms of treatment of this rare fracture-dislocation: (1) collar-and-cuff sling; (2) disregard dislocation and apply Velpeau bandage without further treatment; (3) long-arm cast in full extension; (4) traction; and (5) open reduction and internal fixation of the olecranon after excision of the head of the radius. Surgical treatment was elected, and at the time of operation it was already apparent that this fracture was extraordinarily unstable. In part this was attributed to the extensive damage of the soft parts, including the brachialis anticus, biceps brachii and triceps, as well as the anterior capsule with disruption of the orbicular and the lateral collateral ligament. The marked comminution of the olecranon process, involving at least two thirds of the trochlear notch as well as the radial head and neck, discouraged all attempts to restore a functional ulnar joint surface. Therefore it was practicable only to consider excisional surgery of the olecranon in accordance with the objectives outlined by McKeever and Buck.[11] When the displaced fragments of the olecranon process were removed, 30 per cent of the distal vertical articular segment of the semilunar notch remained to articulate with the humeral trochlea. According to McKeever and Buck, 80 per cent of the semilunar notch can be excised without deleterious effects

Of course, when removed, the fragmented radial head left a large defect in the lateral side of the elbow. The shredded triceps and forearm extensor tendons gave no internal support. Obviously, some other form of internal fixation had to be used in combination with a plaster encasement to provide stability and prevent recurrence of the redislocation. The intra-articular Kirschner

wire was tried and found to offer excellent fixation and an additional advantage of pull-out method.

Olecranon

The fracture of the olecranon formed the largest part of the injury to the elbow joint in this case, and, for the sake of discussion, it may be considered as if it were a single injury. Prior to the days of aseptic surgery the usual position of immobilization for this type of fracture was full extension for from 4 to 6 weeks. In 1884, Lister selected a fracture of the olecranon to perform the first open reduction by his method of antisepsis. Prior to that time, full extension seemed to be the only position in which adequate reduction of the fracture could be maintained. The resulting stiffness of the elbow led to the adoption of the position of mid-flexion. However, almost invariably this produced nonunion of the fracture owing to the wide separation of the fragments, with a persistence of disappointing and ungratifying results.

Dunn[5] observed that fractures of the olecranon process were fraught with complications and advocated treatment by removing the detached fragment and reattaching the triceps expansion to the upper end of the shaft of the ulna. In general, the use of this treatment of olecranon fractures depends largely upon the amount of separation of the fragments and the age of the patient. The two aims of treatment should be (1) to restore the power of active extension and (2) to retain a maximum range of painless motion of the joint. When there is less than 0.5 cm diastasis of the fragments, which does not increase with flexion of the elbow to right angle, or, if there is active extension of the elbow against gravity, the treatment may be conservative. However, if wide separation of the fragments exists and increases upon flexion of the elbow, or if there is no active extension against gravity, operative treatment usually is indicated. If the patient is elderly or if some definite contraindication exists, such as an infected laceration or abrasion overlying the fracture site, conservative treatment is a wise policy.

Today it is accepted almost unanimously that an open operation is advisable when there is separation of the olecranon fragments exceeding 0.5 cm. and the injury is a compound fracture. Other reasons for advising an open operation in these fractures are that (1) irregularity of the joint surfaces, if not corrected, later will cause pain, restricted motion and the development of traumatic arthritis; (2) separation of the proximal fragment from the distal caused by elongation of the triceps tendon will decrease the strength of the tendon; and (3) in young and middle-aged individuals who need a strong and movable elbow operative repair will offer a more certain and rapid opportunity of obtaining good results. In elderly individuals who do not require a heavy-duty elbow and in growing children, operation usually is not indicated unless the fracture is part of an open injury.

Today three generally accepted methods are available, and each is indicated under different conditions:

1. **Circumferential or Figure-of-Eight Suture Fixations.**[1,2,9,13,14,15] In isolated injuries of the olecranon process which are not comminuted and are well proximal to the level of the coronoid process, this method seems particularly applicable. It is very important that the olecranon fragments be repositioned meticulously and anatomically, any tilting or incongruity of the articular surfaces being avoided. In comminuted fractures this procedure generally is not applicable.

2. **Intramedullary Fixation.**[8,16,17,22] This method seems to be particularly effective for internal fixation of transverse fractures of the olecranon.

3. **Excision.**[6,7,11,12,19,20] *Excision of the* proximal fragment or fragments offers two great advantages for treatment of commi-

nuted fractures. (1) It eliminates the possiblity of nonunion and (2) it reduces the hazards of traumatic arthritis from incongruity of the articular surfaces to some extent. While this method is more widely approved today than it was 20 years ago, the preponderance of opinion holds that excision of the olecranon fragments should not be adopted as routine operative procedure in early cases. The use of this procedure seems to be entirely contingent upon a sufficient amount of olecranon to form a stable base with the trochlea.

The literature on surgical excision of the olecranon has been reviewed in detail since the operation was found to be successful in 1918 by Follie and investigated by McKeever and Buck[11] and many others[5,6,12-21] since World War I. Nearly all observers were surprised to find good results following excision of the olecranon and plastic repair of the triceps when the proximal fragment included only the vertical part of the semilunar notch and good position could not be obtained by closed or even open reduction. The operation was advised also when small subcutaneous fragments caused tenderness in the elbow or a pseudarthrosis developed after other treatment. Partial resection of the olecranon was employed even in comminuted fractures of the olecranon with depressed areas of the joint surface. Early mobilization was adopted to avoid triceps atrophy and aid early recovery of motion.

Objections that have been raised to this type of treatment are that removal of large portions of the olecranon process (1) gives rise to lateral instability of the joint; (2) results in a less efficient elbow; (3) removes protection to the posterior aspect of the elbow; (4) impairs the power of the triceps muscle; and (5) eliminates the last few degrees of extension of the elbow.

Wainwright[21] found in his series that only one case demonstrated any lateral instability. In this instance the fracture involved the coronoid process and the plateau for reception of the lower end of the humerus. It has been demonstrated on the cadaver that the stability of the elbow joint is not dependent upon the presence of the olecranon process in the olecranon fossa but on the integrity of the upper surface of the coronoid process and the lateral ligaments of the elbow joint. Apparently, weakness of the triceps may be avoided by tight repair of the triceps tendon. Watson-Jones[22] pointed out that the essential part of this operation was not the excision of the olecranon but the repair of the triceps tendon. He used strong mattress sutures which were passed through the triceps, guided through a drill hole in the ulna and tied securely. Further fixation was achieved by suturing the triceps tendon to muscles and fascia on each side of the ulna. When there is an associated forward dislocation of the joint, excision of the olecranon is contraindicated, since this injury predisposes to redislocation.

Radius

Excision of the head and the neck of the radius is regarded generally as the best form of treatment for the badly comminuted or displaced fractures. However, excisional surgery is not without its limitations and should be reserved only for adult individuals. Sutro[19] described regrowth of nodular, deformed, flattened or expanded ectopic bone at the proximal end of the radius following resection. In one case, regrowth recurred and necessitated a third resection 15 months after the second. Buxton,[3] in reporting on a series of 100 fractures about the elbow, resected four of the radial heads. Whenever possible, he recommended reposition of the radial head, especially in children, since resection at times resulted in extreme cubitus valgus. Other complications incurred included limitation of wrist motion, radial deviation of the hand and prominence of the distal end of the ulna.

Lewis and Thibodeau[10] observed wrist deformity following resection of the radial head and neck for badly comminuted fractures; Cubbins, Callahan, and Scuderi[4] expressed their disapproval of the free removal of the radial head in the treatment of frac-

tures about the elbow, because the radius constitutes a support for the ulna if the distal radio-ulnar joint is intact.

Key and Conwell[8] noted the peculiar functional anatomy of the elbow joint, in which the radial head moves across the capitellum in flexion and extension of the elbow and also rotates approximately 160° on the ulna and on the capitellum in pronation and supination of the forearm. Thus, to restore full motion to a joint with this complex system, the repositioning of the fragments must be as nearly normal as possible. If this cannot be achieved and the displaced fragments *comprise one third or more of* the articular surface, the entire radial head should be removed up to the bicipital tuberosity. Speed and Knight[17] found that the results of partial excision of the head of the radius, even on the rare occasion when it might be feasible, were not as good as those of total excision.

SUMMARY

1. This is a report of a rare case to illustrate the principle that comminuted fractures of the elbow, ordinarily resulting in pain and great loss of motion of the joint, can be treated by excisional surgery better than by any attempt to reconstruct the irreparably damaged articular surfaces. The use of the Kirschner transarticular wire for internal fixation and for maintaining correct anatomic relationships until the joint capsule, tendons and other soft parts had healed was instrumental in achieving early recovery and rehabilitation of this patient.

2. A pseudarthrosis or fibrocartilaginous surface on the ulnar side of the joint and a true articular cartilage on the humeral side of the joint provided a good functional system for a *non-weight-bearing joint in* a middle-aged man.

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Fractura e Dislocation del Radius e del Ulna al Articulation Cubital

Summario in Interlingua

Es reportate un rar fractura-dislocation del radius e del ulna al articulation cubital, tractate per excision chirurgic e transfixation temporari per medio de un filo metallic de Kirschner. Le question de tractamento conservatori o chirurgic es discutite con referentia al caso presente e in general. Le aspectos e problemas exceptional per le lesion combinate de dislocation e fractura in radius e ulna es examinate in le lumine de un revista general del litteratura.

Le principio es illustrate que fracturas comminutive del cubito, que resulta ordinarimente in dolores e un grande perdita de mobilitate articular, es melio tractate per excision chirurgic que per le tentativa de reconstruer le irreparabile superficies articular. Le uso del filo transarticular de Kirschner pro fixation interne e pro mantener correcte relationes anatomic usque le capsula articular, le tendines, e altere partes molle esseva curate determinava le successose e prompte restablimento e rehabilitation del presente patiente.

Un pseudo-arthrosis o superficie fibrocartilaginose al latere ulnar del articulation e un ver cartilagine articular al latere humeral del articulation provideva un bon systema functional pro un articulation sin carga pesante in un homine de etate medie.

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Congenital Scoliosis Without Vertebral Anomaly

The Vertebral Histology of Two Cases*

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Congenital scoliosis without genetic malformation of one or more vertebrae occurs infrequently. When present, it is usually associated with heart disease, congenital anomalies of the thoracic viscera or congenital defects of the diaphragm.[5,11,12,15,20] Rarely it may be found without apparent associated anomalies.[13] At times the cardiac or the pulmonary defects are severe enough to cause early death. Recently, two such cases became available for study. They offered an unusual opportunity to continue our investigation of the relationship of scoliosis to vertebral development.

Previous studies have drawn attention to the diaphyseal growth plate of the vertebral body as a possible etiologic focus for idiopathic scoliosis.[3,4,9,17] In brief, these studies demonstrated the presence of columnar growth plates at the cephalic and the caudal ends of the vertebrae, though not overlaid by true epiphyses. It was suggested that these growth plates were subject to the same intrinsic and extrinsic influences as similar growth plates at the ends of the long bones[3] Such influences may be those of asymmetric development, the abnormal pressure of muscular or postural imbalance, the effect of infection, faulty metabolism or local vascular derangement.[1,14]

Our two present cases demonstrate several further histologic observations on the subject. To our knowledge, these have not previously been described at so early a period in the development of the deformity. Of course, in these cases scoliosis is secondary to extensive visceral and diaphragmatic abnormalities. However, since one was a stillbirth, more or less at term, and the other a 4-month-old infant, as yet no postural or gravitational forces were superimposed on the axis of the spinal column. Therefore, any deviation from normal structure was due to forces within the body and could not be related to extrinsic gravitational or other pressures.

Case I. Male fetus, white, 41 cm. in length, stillborn at 37 weeks. Almost all the abdominal viscera were lying outside the abdominal cavity in an externalized transparent sac. There was agenesis of the left diaphragm, and on the right side a small posterior diaphragmatic leaf was exposed. Only pleura and peritoneum separated the abdominal from the thoracic contents. The left lung was very small and compressed to a greater degree than the right. The heart was not remarkable. Eleven pairs of ribs flared out at the costochondral junction. Other individual organs were not significantly abnormal, though greatly misplaced.

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Fractura e Dislocation del Radius e del Ulna al Articulation Cubital

Summario in Interlingua

Es reportate un rar fractura-dislocation del radius e del ulna al articulation cubital, *tractate per excision chirurgic e transfixation* temporari per medio de un filo metallic de Kirschner. Le question de tractamento conservatori o chirurgic es discutite con referentia al caso presente e in general. Le aspectos e problemas exceptional per le lesion combinate de dislocation e fractura in radius e ulna es examinate in le lumine de un revista general del litteratura.

Le principio es illustrate que fracturas comminutive del cubito, que resulta ordinarimente in dolores e un grande perdita de mobilitate articular, es melio tractate per excision chirurgic que per le tentativa de reconstruer le irreparabile superficies articular. Le *uso del filo transarticular de Kirsch*ner pro fixation interne e pro mantener correcte relationes anatomic usque le capsula articular, le tendines, e altere partes molle esseva curate determinava le successose e prompte restablimento e rehabilitation del presente patiente.

Un pseudo-arthrosis o superficie fibrocartilaginose al latere ulnar del articulation e un ver cartilagine articular al latere humeral del articulation provideva un bon systema functional pro un articulation sin carga pesante in un homine de etate medie.

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Congenital Scoliosis Without Vertebral Anomaly

The Vertebral Histology of Two Cases*

EDGAR M. BICK, M.D., ERNEST S. BARASH, M.D., AND LOTTE LEHMAN, M.D.

Congenital scoliosis without genetic malformation of one or more vertebrae occurs infrequently. When present, it is usually associated with heart disease, congenital anomalies of the thoracic viscera or congenital defects of the diaphragm.[5,11,12,15,20] Rarely it may be found without apparent associated anomalies.[13] At times the cardiac or the pulmonary defects are severe enough to cause early death. Recently, two such cases became available for study. They offered an unusual opportunity to continue our investigation of the relationship of scoliosis to vertebral development.

Previous studies have drawn attention to the diaphyseal growth plate of the vertebral body as a possible etiologic focus for idiopathic scoliosis.[3,4,9,17] In brief, these studies demonstrated the presence of columnar growth plates at the cephalic and the caudal ends of the vertebrae, though not overlaid by true epiphyses. It was suggested that these growth plates were subject to the same intrinsic and extrinsic influences as similar growth plates at the ends of the long bones.[3] Such influences may be those of asymmetric development, the abnormal pressure of muscular or postural imbalance, the effect of infection, faulty metabolism or local vascular derangement.[1,14]

Our two present cases demonstrate several further histologic observations on the subject. To our knowledge, these have not previously been described at so early a period in the development of the deformity. Of course, in these cases scoliosis is secondary to extensive visceral and diaphragmatic abnormalities. However, since one was a stillbirth, more or less at term, and the other a 4-month-old infant, as yet no postural or gravitational forces were superimposed on the axis of the spinal column. Therefore, any deviation from normal structure was due to forces within the body and could not be related to extrinsic gravitational or other pressures.

Case 1. Male fetus, white, 41 cm. in length, stillborn at 37 weeks. Almost all the abdominal viscera were lying outside the abdominal cavity in an externalized transparent sac. There was agenesis of the left diaphragm, and on the right side a small posterior diaphragmatic leaf was exposed. Only pleura and peritoneum separated the abdominal from the thoracic contents. The left lung was very small and compressed to a greater degree than the right. The heart was not remarkable. Eleven pairs of ribs flared out at the costochondral junction. Other individual organs were not significantly abnormal, though greatly misplaced.

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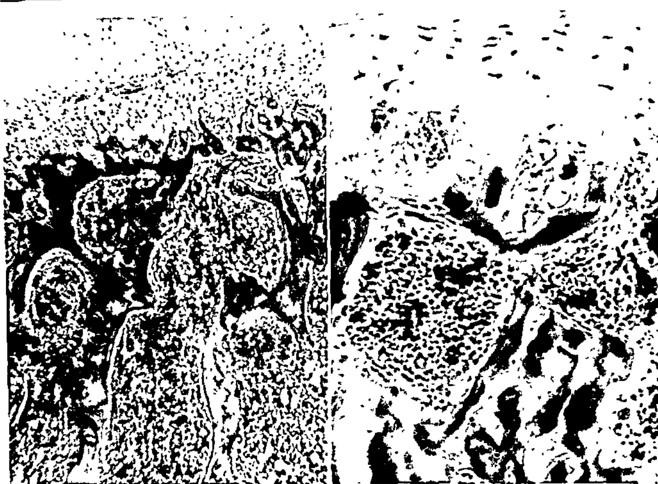


FIG. 2. High-power views of growth plate area of concave side of vertebrae at apex of curve.

tebral bodies at this stage of development.[10] Of particular interest to the senior author was his failure to discover any perceptible asymmetry in the width or the structure of the columnar layer of the growth plate in any samples of the section.

In Case 2, aged 4½ months, the appearance was more specific. Not only was there greater compression of the annulus on the concave side but the nucleus pulposus lay farther off center to the convex side. The unilateral compression of the disk space, in so young a spine, still was measurable in millimeters but showed a greater order of difference. Measurements of the intervertebral space one space above the apex of the curve, at the apex, and one space below were, respectively, concave side, 2, 2 and 2 mm., and convex surface, 4, 3 and 4 mm.

The arrangement of the fibers of the annulus about the nucleus pulposus was similar to that described in the first case, but it was more markedly concentric and dense on the convex side. The fibers appeared not at all concentric and relatively more sparse on the concave. The ossific mass of the vertebral body at the apex of the curve was wedged, but no visible evidence of trabecular compression or increased trabecular density was observed. It must be emphasized here that in these newborn and infant spines no superincumbent weight had as yet been applied. Here too, no abnormality or asymmetry of the columnar growth plate could be discerned.

Atrophy of the annulus fibrosus on the concave side of the curve and a shift of the nucleus pulposus to an eccentric position toward the convex side suggest the possibility, if not the probability, that the transi-



FIG 1. From male fetus, stillborn, 37 weeks.

There was a marked curvature of the spine displaced to the left The apex of the primary curve was at the thoracolumbar junction

Case 2. Female, white, aged 4½ months. Brachycephalic head with a soft 4-cm mass over the right occiput. The right lung was compressed and atelectatic. The heart was enlarged and globular with conspicuous enlargement of the right ventricle The heart and its associated great vessels presented a number of congenital and acquired structural abnormalities. A right hydronephrosis appeared secondary to a uteropelvic stenosis.

There was a curvature of the thoracic spine, convex to the left.

The spines of both cases were removed for histologic study. Sections of several vertebrae from each spine were cut in the coronal plane to exhibit internal surfaces perpendicular to the deformity.

In Case 1, that of the stillborn fetus, the vertebral bodies showed no wedging. However, at the apex of the curve, the intervertebral disk spaces displayed distinct compression of the annulus on the concave side (Fig. 1). Three successive intervertebral spaces were measured: one space above the apex of the curve, at the apex, and one space below. These measurements were, respectively, 2, 2 and 2.5 mm. on the concave side and 2, 3 and 2.5 mm. on the convex. It is difficult to establish the points of reference for such measurements in the newborn infant, since the small size and rounded margins of the cephalic and the caudal surfaces of the vertebral body present no linear edge However, these figures represent the order of difference.

High-power studies of the intervertebral disks reveal an almost amorphous nucleus pulposus, elliptic in contour, eccentric toward the convex side. Between the convex edge of the nucleus and the homolateral ligament, the fibers of the annulus were somewhat tightly packed and lay in concentric layers as though being pressed between the two tissues. Toward the concave side the nuclei of the fibroblasts were less tightly packed (i.e., less cellular density) and did not appear to be concentric about the nucleus pulposus.

Within the ossific mass of the adjacent vertebral bodies the trabeculae appeared to be normal. One or two areas of trabeculation reaching into the articular cartilage did not differ from similar views in normal ver-



FIG. 4. High-power views of growth plate area of convex side of vertebrae at apex of curve.

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Fig. 3. From female, aged 4½ months.

tion of a functional to a structural curve may follow such asymmetric pressure on the fibrous tissue of the intervertebral disk.

DISCUSSION

In the normal infantile spine the mobile nucleus can be shifted at will by bending the column. The fixed eccentric transposition of the nucleus pulposus to the convex side and compression of the annulus fibrosus on the concave side of a scoliotic spine were well known to the students of the subject during the latter decade of the 19th century and the early 20th. Lewis Sayre,[16] Bradford,[6] Schultess,[18] Hoffa,[10] Schmorl,[17] Farkas[9] and Steindler[19] all discussed their appearance in their classic monographs. In recent years, the transposition was obvious to Beadle[2] and to Collins.[7] To the contrary, Bradford and Lovett believed that the nucleus pulposus and other elements of the disk probably showed the earliest changes in the development of the deformity. In more recent years, Collins agreed that the role of disk deformity in scoliosis was rather passive than active.

All these authors were discussing the gross pathology of established cases of idiopathic scoliosis in older children. None discussed the histology of the disks in relation to the growth plates in early non-weight-bearing spinal deviations. Certainly, none described a case such as Case 1 in which wedging of the ossific mass of the vertebra had not as yet occurred, the columnar growth plates were histologically normal, but the nucleus pulposus had already been transposed within the intervertebral space. If further evidence confirms the suggestion of these cases, then Bradford and Lovett may have come close to actuality in their impression that the disks showed the earliest changes.

Observations of two cases of congenital scoliosis without vertebral anomaly hardly warrant broad theorizing in the etiology of idiopathic scoliosis. However, necropsy specimens of infantile scoliotics of any type are rarely obtainable in these days of lifesaving pediatrics. Of course, it is anticipated that in time other contributory cases will appear. In the meanwhile, the histologic study of these two cases suggests that the primary factor in converting a functional into a structural scoliosis may be a unilateral defect of the intervertebral annulus fibrosus or a developmental asymmetry of the nucleus pulposus. Structural changes in the ossific mass of the vertebra and its growth plates may be quite secondary.



FIG. 4. High-power views of growth plate area of convex side of vertebrae at apex of curve.

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Scoliosis Congenite sin Anomalia Vertebral

Summario in Interlingua

In le curso del passate dece annos, le etiologia de scoliosis ha essite reinvestigate seriemente. Un gruppo de investigatores cerca le responsa intra le structura vertebral mesme. Inter le possibilemente pertinente alterationes primari le autor signala un asymmetria fixe del discos intervertebral.

Duo casos de scoliosis congenite sin anomalia vertebral esseva disponibile pro le studio histologic e permitteva observationes in re le mechanica del alterationes in le structura vertebral ante le imposition de pesos.

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Metastatic Malignant Melanoma in Bone*

THOMAS A. MARTIN, M.D.†

According to R. A. Willis,‡ melanoma simply means melanin pigmented tumor. Much of the confusion regarding the histogenesis of such tumors has arisen from supposing them all to be of similar origin; that is, all mesodermal, epithelial or neuro-ectodermal. At the outset, let us abandon this assumption and consider separately the several groups of melanotic tumors according to their sites of origin. The principal sites of these in mammals are the skin, the eye and the leptomeninges. There is no reason to suppose that normal melanin production in these three sites and some subsidiary ones (i.e., certain nerve cells) is subserved by cells of similar nature or origin. The basal cells of the epidermis, the pigmented cells of the retina, the dendritic pigmented cells of the choroid and of the meninges and the nerve cells of the substantia nigra have no close affinity, and yet they are all melanin producers. Clearly, then, we should consider the melanoma of various tissues separately and not force them together artificially in accordance with this or that hypothesis regarding the specificity of melanoblasts. Melanoblasts are not cells of a specific type but are of as many and diverse kinds as there are different tissues capable of producing melanin. Fortunately, melanoma is a relatively rare disease. Most people have one or more pigmented moles on the body, and only an infinitesimal fraction of the total number of these will produce melanomas.

The two cases discussed in this chapter represent the type of melanoma arising from skin. These tumors occur at all ages; however, about 75 per cent develop between the ages of 30 and 70 but without special predilection in any particular decade. They are rare in young children. Males and females are affected about equally, and in the two cases under discussion one was a male and one a female. In reviewing the literature it was very difficult to find much on the subject of melanoma metastasizing to bone or to obtain much in the way of statistics. However, Geschickter and Copeland§ found 3 cases in a series of 169 melanomas, or a percentage incidence of 1.07.

CASE REPORTS

Case 1. A female, aged 59, was admitted to the hospital by a general surgeon, October 15, 1948, because of a growth on the inner aspect of the right heel. The growth was first noticed 3 years previously and had increased in size and become more tender during the 8 weeks before admission. Some 22 years prior to this admission the same surgeon had removed a growth from the right heel and had obtained a pathologic diagnosis of fibrosarcoma. The patient had had no trouble until this recurrence in 1948.

* Presented at the meeting of The Association of Bone and Joint Surgeons held in Palm Springs, Calif., March, 1958.

Photographs by Mr. James MacKenzie, Maine Medical Center, Portland, Maine

† Portland, Maine.

‡ Willis, R. A.: Pathology of Tumors, St Louis, Mosby, 1948.

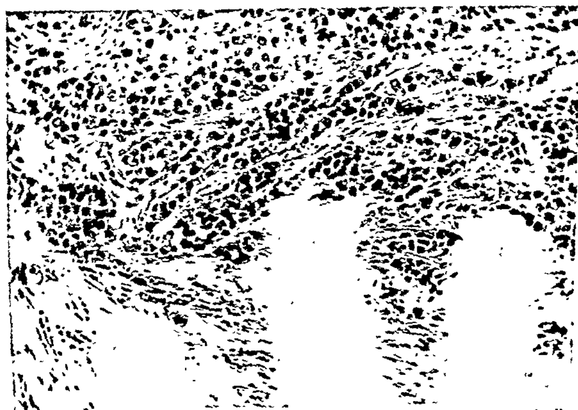
§ Geschickter, C F, and Copeland, M. M.: Tumors of Bone, ed 3, Philadelphia, Lippincott, 1948.

The tumor was removed, and a Thiersch graft from the left thigh was performed with a 100-per-cent "take." The pathologic report in this instance was recurrent fibrosarcoma.

This patient came to my attention on November 13, 1953, when she was readmitted to the same institution for treatment of an ulcerated lesion of the right heel, which had developed a month previously. Despite all home therapy, the lesion had failed to heal, and upon admission to the hospital physical examination was negative except for the right foot. On the medial aspect of the right heel there was a depressed area covered by a skin graft, and immediately posterior to the area there was an ulcerated type of tumor measuring 2½ cm. square bordering the grafted area of skin. The clinical impression was a recurrent fibrosarcoma. A biopsy of this lesion was done on November 17, 1953, and the pathologic report was malignant amelanotic melanoma (Fig. 1). On November 25, 1953, the tumor was removed from the right heel, and a split-thickness skin graft from the right thigh was applied to the area with an excellent take.

The patient did well until February, 1956, when she appeared in my office with a lesion on the medial aspect of the right thigh, which appeared to be firm and adherent and with a dark bluish center that could be seen through the overlying skin. Physical examination also revealed some firm palpable inguinal glands. She was admitted to the hospital for a biopsy, and again the pathologic report was metastatic malignant melanoma. This patient had previously refused amputation, so that an attempt was made to remove the lesion and to skin-graft the area, but it was unsuccessful. The patient was discharged on May 25, 1956, with the lesion on the right thigh still unhealed.

About July 1, 1956, in her home, the patient's crutch slipped and she fell against a dresser, striking her right forearm forcefully against the furniture. This trauma was followed by pain, but there was no swelling or clinical deformity. An anterior splint was applied, and on July 6 she was readmitted to the hospital for further study and treatment. Roentgenograms of the right wrist and forearm were taken on July 13, 1956. These revealed a markedly destructive process involving the lower half of the shaft of the radius which was more suggestive of an osteomyelitis than of tumor at this time. There was considerable nutritional and disuse atrophy of the bone entering into the wrist joint



FIGS 1-3, Cas . 1. Biopsy s elan al cells

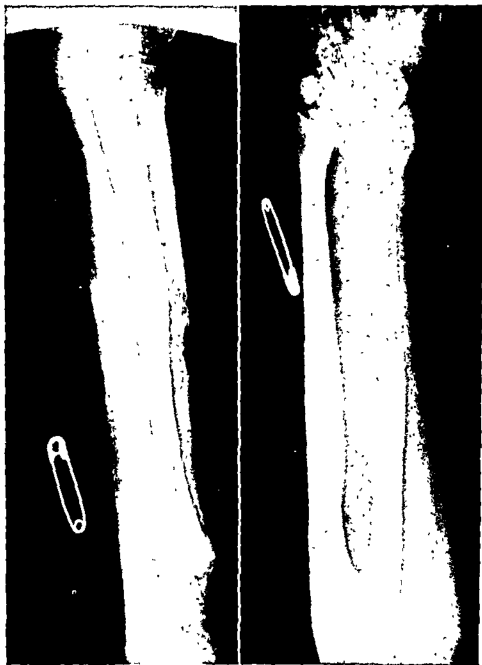


FIG. 2. The osteolytic nature of metastatic melanoma is shown with destruction of the distal half of the right radius.

proper. The entire lower half of the shaft of the radius, with the exception of the lowermost portion, revealed numerous breaks in the continuity of the cortex (Fig. 2). Roentgenograms of the chest at this time revealed no metastasis or pathology. Excision of the recurrent tumor of the right thigh was performed on July 9, 1956, and at this time a considerable amount of the quadriceps had to be removed because of infiltration of the tumor. This was done as a palliative procedure. During the next few months the patient became progressively weaker and experienced considerably more pain.

On September 17, 1956, another roentgenogram of the right forearm revealed progressive destruction of the lower half of the shaft of the radius (Fig 3) From this point on it was evident that the patient was a terminal case, and her course was progressively downward until death ensued on October 22, 1956.

Case 2. This 56-year-old longshoreman first came to my attention on March 19, 1953, when he was referred to the hospital by a colleague because of a tumor on the dorsolateral aspect of the right foot The history revealed that he had had this tumor for a considerable length of time. However, on January 29, 1952, he had sustained a contusion and sprain of the right foot, and since that time the tumor had appeared to increase in size.

Physical examination of the right foot at the

Fig. 3. Showing progressive destruction and malignant nature of the tumor.



Figs 4-12, Case 2

(*Right*) Fig. 4. Anteroposterior views of both os calces The left reveals coarsening of trabeculae and some increased density

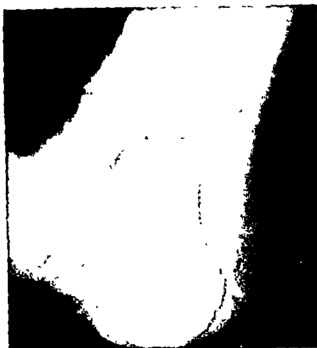


FIG. 5. Lateral view of left heel, revealing increased density of os calcis.

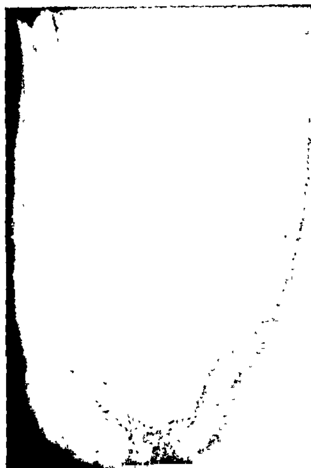


FIG. 6. Extension of process; anteroposterior view with destruction of lateral cortex of os calcis.

time of admission revealed, over the lateral dorsal aspect of the foot, a firm hard tumor which was quite fixed and nontender. Dark bluish streaks could be seen traversing the entire tumor. The skin over the tumor was very thin and of poor texture. The clinical impression at this time was neurofibroma or fibrosarcoma. On March 20, 1953, the tumor was removed and a full-thickness skin graft performed. The pathologic diagnosis of the tumor material removed was myo-epithelioma. However, after some consultation by several pathologists, a diagnosis of malignant metastatic melanoma was made. On April 9, 1953, tumors of the same type were removed from the right clavicular area and from the lateral aspect of the right arm. The patient did well postoperatively, and the skin graft took 100 per cent.

I did not see this man again until he was readmitted to the hospital on August 7, 1956, the chief complaint being his left foot. The history was interesting in that about a year and a half previous to this time he had struck his left foot in a fall against a deck housing on a ship while employed as a longshoreman. Physical examination was negative upon admission except for some small tumors on both lower extremities in the region of the thigh, the knees and the left heel The left ankle revealed swelling, and there was thickening of the left os calcis with tenderness to deep palpation and percussion. The thickeni...



FIG. 7 Lateral view of os calcis showing



FIG 8. Punch biopsy specimen showing invasion of os calcis by tumor cells.

malleolus on the lateral aspect of the os calcis. [illegible] oot and [illegible] oarsen- [illegible] the os calcis over its posterior two thirds There was unevenness and raggedness of the upper surface of the bone Considerable calcification of



FIG. 9 Showing gross pathology of the tumor involving the left os calcis (amputated specimen).



FIG. 10 Reveals depression in floor of right orbit with involvement of right maxillary sinus.



FIG. 11. Waters view of skull showing destruction of malar bone and osteolytic and osteoblastic character lesion.



FIG. 12. Lateral view revealing extensive destruction of the sphenoid.

the foot arteries was noted (Figs 4 & 5). At this time a short leg cast was applied, and the patient was supplied with crutches and discharged.

At the end of 6 weeks the cast was removed, and the foot appeared to be about the same so far as clinical examination was concerned. In November, roentgenograms again were taken of the os calcis, and at this time there was considerable destruction or breaking through of the cortex, especially on the lateral aspect of the bone (Figs. 6 & 7). Punch biopsy established a diagnosis of malignant metastatic melanoma (Fig. 8). A below-knee amputation was performed on December 31, 1956 (Fig 9). The patient was discharged on March 16, 1957, using crutches and apparently doing quite well. However, he was readmitted on June 17, 1957, the chief complaint being pain in and around the right orbit. Upon admission the patient had proptosis of the right eye with overhanging of the edematous conjunctiva. Roentgenologic examination of the right orbital region showed irregularity of the lower half of the outline of the orbit with some depression of the floor. There was irregular involvement into the right maxillary sinus, which was somewhat dense The right orbital foramen appeared to be enlarged (Fig. 10). The impression was that this was an extension of the melanoma into the surrounding bone. After consultation with the Eye and X-ray Services it was decided that this patient receive some deep therapy, which resulted in almost immediate retraction of the eye, loss of the edema and subsidence of the pain. After this series of x-ray treatments the patient was discharged improved.

He was again admitted to the hospital on October 10, 1957, because of severe headache and pain referred to the right orbital area. Upon this admission there was not any evidence of proptosis of the right eye, but the patient was totally blind. Roentgenologic examination of the skull revealed again marked destruction of the malar bone and involvement of the lateral aspect of the maxilla on the right side with diffuse clouding of the right maxillary sinus. For the most part, the lesion involving the malar and the right maxillary bone appeared to be osteolytic in character, although there was some density in the lateral margin of the right maxillary sinus suggesting an osteoblastic character. There was noted some increase in density in the right orbit, due probably to superimposed soft-tissue shadows. On the lateral views and the occipital views there was evidence of extensive destruction of the greater wing of the sphenoid on the right side. These changes were some-

what more marked than shown in the examination of June 4, 1957 (Figs. 11 & 12). A chest roentgenogram taken at this time revealed marked elevation of the left hemidiaphragm which was not present on previous examinations. This had a somewhat nodulated character on the lateral views. A possibility of metastasis beneath the diaphragm was considered There was no definite evidence of pulmonary metastasis at this examination. The patient was discharged again from the hospital on October 27, 1957, and was readmitted January 27, 1958, in terminal condition. He expired February 1, 1958.

The results of the postmortem examination in this case were extremely interesting No visceral metastases were found. A 4,500-Gm. tumor of the left flank was found along the lateral gutter compressing the left kidney. This probably accounted for the findings in the last chest plate taken. Definite tumor was found in the anterior cranial fossa involving the cavernous sinus, the sphenoid sinus and the orbital ridge. Histologically, both pigmented and nonpigmented cells were found.

SUMMARY

Two cases of malignant metastatic melanoma have been presented, one a female and one a male, and the pathology discussed. It is obvious that melanomas exist for long periods of time before becoming malignant and metastasizing. Metastasis appears to be both by the lymphatics and the blood stream. Although one must be careful in attributing cause and effect of trauma in relation to tumors, it is suggested that in both these cases trauma may have played a part. In the first case, the patient had trauma to the right forearm which became involved with tumor. In the second case, a history of a sprain and contusion of the foot in which a tumor was found was noted. I believe that these two cases also illustrate the type or the character of the tumor found in the bone which in the second case was both osteolytic and osteoblastic. It was interesting to find that in the second case there was no visceral involvement, as is usually the case in malignant metastatic melanoma. These two cases were also extremely interesting to the author from the standpoint of the low incidence of bony metastasis in this type of tumor.

Metastatic Melanoma Maligne in Osso

Summario in Interlingua

Es presentate duo casos de melanoma metastatic in osso, le un mascule e le altere feminin, ambes tractate per le autor in su practica in un communitate de magnitude moderate in le Stato de Maine. Le definition de melanoma como "tumor a contento de melanina" ha resultate in multe confusion e le supposition que omne melanomas es histogeneticamente identic, i.e. que illos consiste semper de un unic e specific typo de cellulas que se distingue per lor production de melanina In le presente articula le autor signala que melanina es producite per differente typos de cellulas ab varie histos del corpore, ben que primarimente ab le pelle, le oculos, e le leptomininges. In certe casos, cellulas nervose se ha monstrate capace a producer melanina, con le resultato que multe investigatores ha concludite que melanomas evolve ab histos neuro-ectodermic. Le autor assere que melanoblastos non es cellulas de typo specific, e ille presenta un lista del areas del corpore in que melanomas ha demonstratemente occurrite. Le casos describite in le presente articulo exhibiva melanomas a origine in le pelle sed con metastase al osso. Le historia del duo casos es significative, viste le longe intervallo ab le disveloppamento del melanoma usque al apparition del lesion metastatic in le osso.

Roentgenographias e *histomicrophotographias* es presentate pro ambe casos. In un del casos, un examine necroptic esseva effectuate e resultava in interessantissime constatationes. Le absentia de affectiones visceral in iste caso—illo del patiente mascule—esseva un *surprisa pro le autor e debe esser considerate como inusual. Super* le base de su experientias in iste duo casos, le autor exprime su opinion que le presentia de melanoma debe suggerer le suspicion de possibile metastases ossee. Isto es un aspecto que ha essite negligite in le passato.

26

The Intramedullary Internal Fixation of Intertrochanteric Fractures

DUNCAN C. MCKEEVER, M.D.*

Therefore go forth companion when you find
No highway more, no track all being blind,
The way to go shall glimmer in the mind.†

In 1951, a 96-year-old female fractured the intertrochanteric area of her femur (Fig. 1, *left*). It was my intention to apply some type of blade plate. On exposure of the fracture, the area between the base of the neck and the lesser trochanter was found to resemble broken eggshell. No remaining fragment was more than 1 or 2 cm. in size. The application of any type of blade plate seemed likely to leave a wide gap between the two main fragments of the bone. Therefore, a long Smith-Petersen nail was selected and driven through the remnant of neck into the head. The other end of the nail was dropped into the medullary canal of the distal fragment, and the two fragments were allowed to telescope together over the nail. This placed the head and neck fragment on the shaft in a position of marked valgus. The incision was closed. A plaster boot with lateral extension was applied to prevent external rotation.

The patient made an uneventful recovery. She was up in a wheel chair within a few days. Roentgenograms taken at 6 weeks (Fig. 1, *right*) indicated the presence of bony union. Weight-bearing was instituted. The patient regained rapidly the ability to walk without assistance. A 1-inch heel elevation enabled her to compensate for the difference in length and to walk with almost no limp.

Approximately 2 years later the same method was used in a similar case (Fig. 2). There was much more comminution. Two large fragments were fastened to the shaft with screws. Unusually rapid healing of the fracture occurred; weight-bearing was started at 8 weeks, and it could have been started earlier.

These and other clinical observations have led to the following conclusions:

The rate at which fractures can heal under optimum conditions is not known. There is no physiologic reason for their not healing in much less than the usually accepted period. Under ideal conditions this healing time may be 3 weeks or less. To date, we do not know how to bring these conditions about in a given fracture; we do not even know exactly what they are.

Subsequent to the two cases cited, an attempt was made to design a suitable device by means of which such total intramedullary fixation could be secured in every fracture of the femur from the base of the neck to the level of the lesser trochanter. The design was intended to prevent torsion without other fixation and to increase the angle between the neck and the shaft, placing the head in a valgus position.

All blade plates have one biomechanical fault; they do not permit progressive compression. The only way in which a fracture can be subjected to compression stress is when the nail portion of the fixation penetrates the head farther. The sliding nail, such

* Houston, Texas

† Masefield: Poems, "The Ending," New York, Macmillan, 1935 (copyright Barbara Zucker)

Fig. 1. (*Left*) Fractured intertrochanteric area of femur in 96-year-old woman. (*Right*) Six weeks after operation.

as the Pugh, gets away from part of this mechanical fault, but not all of it. Sliding is accompanied by a shearing action. The only device that will avoid all the biomechanical faults and permit rapid healing is a self-retaining total intramedullary fixation. In order to promote rapid healing, it should place the head and neck fragment in a more than normal valgus angle to the shaft. This angle should be as great as is possible without causing dislocation of the femoral head The problem is not only to make a device that will do these things but to design it so that its insertion will be possible without resort to black magic.

Such a device was designed (Fig. 3), and after 2 years of pleading with a manufacturer 3 trial samples were produced. These and three subsequent ones have been used with



Fig. 2. Eight weeks after operation in a case similar to that depicted in Figure 1.

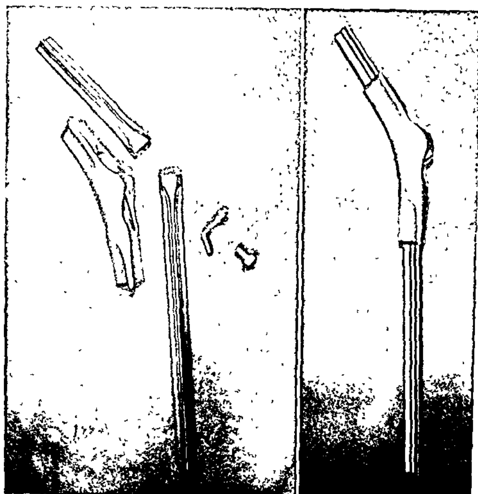


FIG. 3. Device (*left*) disassembled and (*right*) assembled.



FIG 4 (*Left*) Total intramedullary intertrochanteric fracture fixation. (*Right*) Lateral view of total intramedullary intertrochanteric fracture fixation.

uniformly good results and with very rapid healing (Fig. 3).

The patient in Figure 4 had the device inserted the day after she sustained fracture. She went home from the hospital 2 weeks later. She began to walk at once without instructions to do so. The surgeon had no idea that she would do so. She continued to walk and made an uneventful recovery. As a routine, weight-bearing may be permitted at 6 weeks and possibly in less time than that.

This method of total intramedullary internal fixation for fractures in the region of the trochanter is presented because it is biomechanically sound, and it places the neck and head in relation to the shaft at such an angle that rapid healing is certain. This has been borne out by the results obtained to date. The device itself is in the process of being simplified, but the principle remains the same. This presentation is a preliminary report. Details of the technic will be reported when the design is final.

SECTION III

ITEMS

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Osteoarthritis of the Hip in a Gorilla

Report of a Third Case

ROBERT M. STECHER, M.D.*

A recent study[1] described two instances of gorilla skeletons with osteoarthritis of the hip, one from the Anatomical Museum of the University of Edinburgh and the other from the Todd Collection of Western Reserve Medical School of Cleveland, Ohio. This chapter will describe a third case discovered at the American Museum of Natural History in New York. The author is indebted to Dr. Harold Anthony, Director of the Department of Mammals, and the staff for permission to report this case.

The two cases previously reported were young or middle-aged adult males. In both the left hip was affected, there was no evidence of arthritis elsewhere in the body, and the best assumption that the authors could make on the evidence available was that the lesions were the result of osteochondritis or of Legg-Calvé-Perthes disease. Only part of the skeleton from the author's case is available—2 femurs, 2 halves of the pelvis, the sacrum, 1 scapula, 1 humerus, 2 radiuses, 1 ulna, the sternum and some of the ribs. Because the bones are short and small, the animal is thought to have been a female. She was mature, because all the epiphyses have been obliterated. No evidence of other arthritis was seen. The head of the left femur is enlarged and flattened, and the neck of the femur is shortened markedly. The acetabulum is greatly enlarged, the roof is slanting, it is very shallow, there is present a false floor which moves the joint laterad, and it is surrounded by a large mass of new bone formation.

The deformities in this case are well demonstrated in the roentgenograms. Figure 1 is of the pelves, showing a full view of the acetabula. The right one is abnormal. It is enlarged appreciably and surrounded by an irregular mass of bone proliferation. The articulating surface also has been increased so as nearly to cover the floor of the fossa, and the surface is roughened and irregular. The posterior half of the joint surface has been punctured by innumerable small holes. The incisura of the acetabulum has been closed and the circle completed by new bone.

Figure 2 is an anterior view of both femurs. The only abnormality is in the head and the neck of the right one. The head is enlarged and flattened, and a large spur is seen on the anterior almost inferior lateral border of the joint surface. The neck seems to have been almost absorbed so that the upper edge of the head is nearly in contact with the shaft. The head has been displaced so as to have had the effect of shortening the femur.

Figure 3 is a medial view of both heads. The right head is seen to have been displaced distally. The abnormal joint surface of the head of the right femur is demarcated clearly by a smooth curving line along the lower surface. The area above this line shows many perforations, varying in size from 0.25 to 2 mm. in diameter. This

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FIG. 1. Acetabula. Left is normal. Right is enlarged, surrounded by new bone formation which also extends across the fossa and closes the acetabular notch

sharply demarcated abnormal area on the head of the right femur seems to have been an area of eburnation, which is matched by a similar area in the acetabulum. The large *roughened area on the head of the normal* left femur perforated by holes is the normal fovea. The right fovea is shown as one large 0.6-cm. hole.

Figure 4 shows the proximal-end view of the femurs of the New York gorilla above and the Cleveland gorilla below. They have been placed so as to have the condyles flat

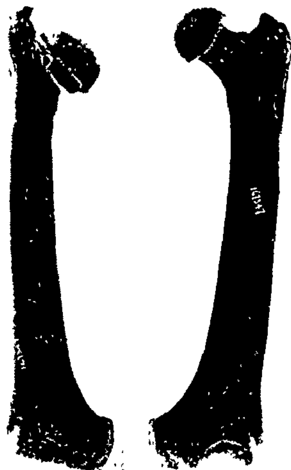


FIG. 2 (*Bottom, left*). Anterior view of both femurs. The left one is normal. The right one shows *enlargement, flattening* and distal displacement of the head upon a very short neck.

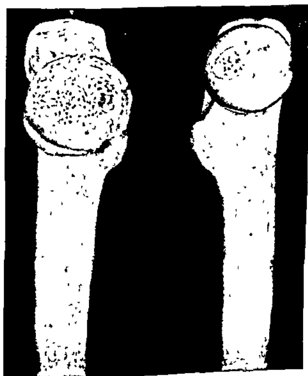


FIG. 3 (*Bottom, right*). Medial view of the heads of both femurs The left is nor- [illegible] apparently the area of eburnation.



Fig. 4. Proximal ends of the femurs of the New York gorilla (*above*) and the Cleveland gorilla (*below*). The difference in size due to sex is obvious. There is 5° retroversion of the femoral neck in the specimens above, 15° anteversion in the specimens below.

Fig. 5. Roentgenogram of the pelvis of the New York gorilla. The right acetabulum is large and shallow, the roof is defective, the fossa is 1.7 cm. from the wall of the small pelvis and the CE angle is 0°. The left acetabulum is normal with an adequate roof, a deep socket and a CE angle of 35°.

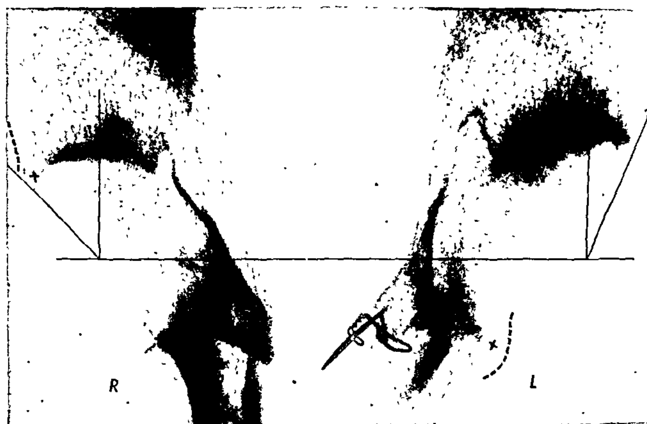


Fig 6. Roentgenogram of pelvis of the Cleveland gorilla showing normal acetabulum of the right hip and diseased acetabulum of the left hip. The roof is barely horizontal, the floor is about 1 cm. from the inner wall of the small pelvis, and the CE angle is 25° compared with 45° on the right.

Table 1. Measurements of Acetabula and Femurs

	Edinburgh Gorilla		Cleveland Gorilla		New York Gorilla	
	Right	*Left*	*Right*	*Left*	*Right*	*Left*
ACETABULUM						
Transverse diameter of brim						
Inner lip	5.5	6.3	5.5	6.5	5.0	4.7
Outer lip	6.4	7.3	7.0	8.0	6.3	5.5
Vertical diameter of brim						
Inner lip	6.1	7.1	5.5	7.5	5.2	4.8
Outer lip	6.1	8.3	6.5	8.5	7.2	5.6
Slipping of brim	Nil	Prominent	Nil	Moderate	Very large	Nil
Depth of fossa below joint surface	0.5	1.5	0 3	1.4	1.5	0.5
Distance—joint surface to inner wall	1.0	1.5	0.8	1.5	1.8	1.0
Erosion of joint surface	Nil	Moderate	Nil	Moderate	Severe	Nil
Greatest width of joint surface	3.0	4.8	3.5	4.5	3.0	3.3
Depth of joint socket	—	—	4 0	4.0	1.7	3 0
FEMURS						
Length to top of trochanter	39.6	38.6	38.0	38.0	32.0	32.0
Length to top of head	—	—	37.0	35 5	30 5	32.0
Diameter of head	—	—	5.2	6 2	4.5	4 0
Height of pelvis	—	—	39.4	—	33.0	—
Average length of 10 gorilla femurs		Male	38.0	Female	33.0	

TABLE 2. MEASUREMENTS OF PELVIS ROENTGENOGRAMS

	NEW YORK GORILLA		CLEVELAND GORILLA		EDINBURGH GORILLA	
	Right affected	*Left normal*	*Right normal*	*Left affected*	*Right normal*	*Left affected*
Diameter of acetabulum (cm.) ...	3.0	2.7	3.2	3.7	3.4	3.4
Angle of roof (degrees)	70	115	120	90	110	70
CE angle (degrees)	0	35	45	25	40	20
Double floor (mm.)	16	2	3	8	5	12

on the table and the shafts parallel. It can be seen that the upper ends of the New York gorilla are in about 5° of retroversion compared with those of the Cleveland gorilla, which are in 15° anteroversion. A roentgenogram of the upper halves of both femurs shows the deformity and the displacement of the head. There is increased bone trabeculation of the head and the shortened neck, but trabeculation is deficient in the upper end of the shaft of the right femur. The cortex of the shaft is much thinner in the right femur than in the left one. This is obvious evidence of disuse.

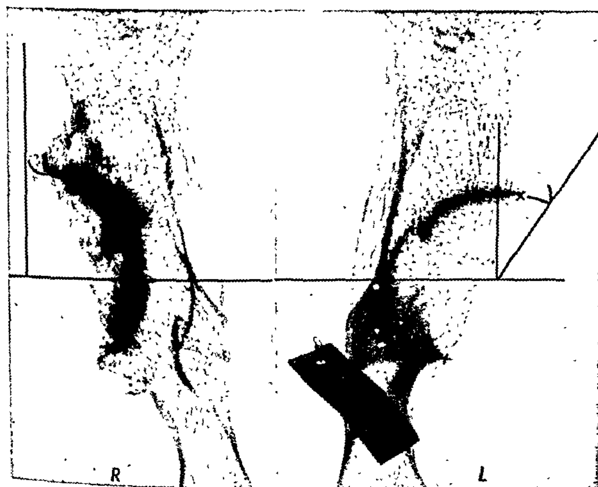


FIG. 7. Roentgenogram of the pelvis of the Edinburgh gorilla. It is printed backward so that the sides are reversed. The normal right hip is on the right The affected left hip shows condensation of the joint surface and an inadequate roof; the floor is 1 cm. away from the inner wall of the small pelvis, and the CE angle is 20° compared with 35° on the right.



Fig. 6 Roentgenogram of pelvis of the Cleveland gorilla showing normal acetabulum of the right hip and diseased acetabulum of the left hip. The roof is barely horizontal, the floor is about 1 cm. from the inner wall of the small pelvis, and the CE angle is 25° compared with 45° on the right.

Table 1. Measurements of Acetabula and Femurs

	Edinburgh Gorilla		Cleveland Gorilla		New York Gorilla	
	Right	*Left*	*Right*	*Left*	*Right*	*Left*
ACETABULUM						
Transverse diameter of brim						
Inner lip	5.5	6.3	5.5	6.5	5.0	4.7
Outer lip	6 4	7 3	7 0	8.0	6.3	5.5
Vertical diameter of brim						
Inner lip	6.1	7.1	5.5	7.5	5.2	4.8
Outer lip	6 1	8 3	6.5	8.5	7.2	5.6
Slipping of brim	Nil	Prominent	Nil	Moderate	Very large	Nil
Depth of fossa below joint surface	0.5	1.5	0 3	1.4	1.5	0 5
Distance—joint surface to inner wall	1.0	1.5	0.8	1.5	1.8	1.0
Erosion of joint surface	Nil	Moderate	Nil	Moderate	Severe	Nil
Greatest width of joint surface	3.0	4.8	3.5	4.5	3.0	3.3
Depth of joint socket	——	——	4.0	4.0	1.7	3.0
FEMURS						
Length to top of trochanter	39 6	38.6	38.0	38.0	32 0	32.0
Length to top of head	——	——	37.0	35.5	30 5	32.0
Diameter of head	——	——	5.2	6.2	4.5	4.0
Height of pelvis	——	——	39.4	——	33.0	——
Average length of 10 gorilla femurs		Male	38.0	Female	33 0	

Hermodsson[2] believes that even in the advanced stage, osteoarthritis of the hip that has developed in a formerly normal joint can be distinguished from that based upon a dysplasia. The difference depends upon the site of the lesion. If decrease in joint space and condensation of joint surface occurs at the top of the femur, it indicates osteoarthritis in a normally developed hip. If there is increased distance between the medial surface of the head and the floor of the acetabulum, the medial type disease is present and the head is forced out of the socket. This indicates disease in an underdeveloped hip or a dysplasia.

Wiberg[1] has devised a method of identifying dysplasias of the hip from roentgenograms of the pelvis. A line drawn from the center of the head of the femur to the lateral edge of the roof of the acetabulum forms an angle with the perpendicular, the CE angle of Wiberg. If this angle is 25° or more, the hip is considered to be developed normally. If it is less than 20°, undoubtedly it is poorly developed or dysplastic. Hips with measurements between 20° and 25° are uncertain and cannot be classified absolutely.

Since roentgenograms were available for all three gorilla pelves, the CE angles were determined for all six hips. In the case here described, the CE angle of the affected right hip is 0° compared with 25° in the normal left one. In the Cleveland gorilla, the CE angle of the affected left hip is 25° compared with 45° in the normal right hip. In the Edinburgh gorilla it is 18° in the affected hip compared with 35° in the normal hip. While there is a wide variation in these measurements, due probably in part to variations in roentgenographic technic, the CE angle is from 17° to 25° smaller in the affected hip compared with the normal one. The greatest difference is seen in the pelvis with the most advanced disease, despite the fact that in the sound hip the CE angle is at the lower limit of normal.

Comparison of these three animals shows that the pathologic changes in the upper ends of the femurs and in the acetabula are fundamentally the same. They differ only in degree. They are more advanced in the present case in respect to the distortion of the head and the neck of the femur, the insufficiency of the roof, of the depth of the acetabulum and the CE angle of Wiberg. In all cases the head has been forced laterad from its normal position in the acetabulum, the characteristic of dysplasia emphasized by Hermodsson. As judged by the CE angle, these animals were all afflicted with dysplasia of the hip that gave rise secondarily to osteoarthritis of this joint.

In the previous study the osteoarthritis was presumed to have resulted from an osteochondritis. It was stated that since the acetabula were large and well developed—each has a sturdy roof and is of normal depth and no erosion is seen of the upper border—congenital dysplasia of the hip was an unlikely possibility. However, congenital dysplasia varies widely in its manifestations. It may be diagnosed at birth or shortly after and develop spontaneously into a normal hip. A hip may be normal at birth and develop dysplasia in the next few years. If these cases were all due to dysplasia, the process seemed to have been arrested in the previously described cases while the deformity, though recognizable, was mild. In the present case the process was severe in the beginning; development of the structures did not keep pace with the necessities of growth, and the deformities increased as age advanced, resulting finally in the condition.

Although evidence is presented here supporting the diagnosis of congenital dysplasia in all three cases, the two previously described may have been the result of osteochrondritis, but such a supposition would seem to be almost impossible in the present case.

CONCLUSION

A female gorilla skeleton is described with advanced osteoarthritis of the right hip, most likely the result of a severe congenital

Figure 5 is a retouched roentgenogram of the pelvis showing both acetabula. The normal one of the left hip, right in the reproduction, shows a horizontal roof. The joint surface is separated from the floor of the pelvis by a small step. The joint surface resumes again at the bottom, about 0.5 cm. away from the floor. The floor of the acetabulum approaches within 0.3 cm. of the inner surface of the small pelvis. These two surfaces joining inferiorly form the U or the teardrop figure, which can be seen opposite the bottom of the joint. A line drawn from the center of the acetabulum to the limbus or the lateral edge of the acetabular roof makes an angle of 25° with the perpendicular.

The diseased hip is in marked contrast with this. The roof of the acetabulum is slanting, the joint surface is continuous around the circumference and uninterrupted from the limbus to the lower area of the lunate surface. No U or teardrop figure is seen, and the surface of the joint is 1.5 cm. away from the inner surface of the small pelvis. The center of the acetabulum is directly below the limbus so that the angle with the perpendicular is zero.

Figure 6 shows the Cleveland pelvis; Figure 7, the Edinburgh pelvis. The comparative data from these three animals are shown in Tables 1 and 2. The average lengths of 10 male and 10 female gorilla femurs and the length of the hip bones of the male gorilla from Cleveland and the female gorilla from New York are included.

DISCUSSION

Three cases of osteoarthritis of the hip have been observed in a survey of 155 gorilla skeletons.* In each instance the hip disease is unilateral and the arthritis monarticular. It affects the left hip in the males and the right hip in the female. These animals were mature but not senile. It can be assumed that this disease was painful, at least part of the time, that it resulted in limitation of motion and deformity, produced laming and some degree of physical disability. It did not interfere with growth or development as judged from the size and the condition of the rest of the skeleton. These animals were able to survive and allow their disease to attain its advanced stage because gorillas are strict vegetarians and need not resort to the chase for food. They live deep in the jungle in small family groups and have no natural enemies.

Since so little is known about hip disease in gorillas, these cases will be discussed in comparison with osteoarthritis of the hip in human beings. Arthritis deformans, malum coxa senilis, osteoarthritis of the hip, congenital dysplasia and congenital dislocation have occasioned great interest and much controversy for many years, and complete agreement about these conditions is still to be attained. The problem of hip disease in man is complicated because osteoarthritis of the joint arises from a variety of causes. In the advanced stage of hip disease, it may be difficult or impossible to identify different antecedent causes. The causes of osteoarthritis of the hip include previous fracture, traumatic dislocation and aseptic bone necrosis, all due to injury. Congenital dysplasia of the hip, coxa plana, slipped epiphysis and osteochondritis or Legg-Calvé-Perthes disease are also followed at times by osteoarthritis In each of these diseases heredity has been suspected or demonstrated. Graber-Duvernay[1] states unequivocably that osteoarthritis develops only on pre-existing deformity of the hip such as subluxation, coxa plana or coxa vara, but this opinion is not accepted universally. Subluxation, osteochondritis and slipped epiphyses are mentioned in many series as precursors of osteoarthritis of the hip.

* The author has examined and made notes on 91 gorilla skeletons in the Todd Collection at Western Reserve University Medical School, one at the Anatomical Museum of the University of Edinburgh, 21 at the American Museum of Natural History, 12 at the Chicago Museum of Natural History, 16 at the Harvard Museum of Comparative Zoology, and 14 at the Smithsonian Institution, a total of 155 skeletons

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Sarcoma Following a Surgically Treated Fractured Tibia

A Case Report

EDUARDO R. DELGADO, M.D.*

A white male, 40 years old, presented imself at the clinic with a history of a fall years previously, when his leg had been truck by an iron tube. At that time he went o a hospital and was operated upon for ractured tibia. Osteosynthesis with plate and screws was performed (Fig. 1). He used a cast for 3 months and then was discharged with slight edema of the leg. He did fairly well for the first two years, but the last year, he had pain on walking and the trouble recurred. In these circumstances the removal

* Havana, Cuba.



FIGURE 1

dysplasia. The acetabulum is enlarged and flat, the roof is inadequate and the CE angle 0° compared with 25° on the normal side. The head of the femur is enlarged and flattened, the surface is perforated in the area of eburnation, the neck has been largely absorbed, and the head is placed 2 cm. distally from its normal position in the proximal end of the femur.

This skeleton is compared with two others, males previously described with similar but less severe deformities, due possibly to congenital dysplasia or osteochondritis.

These three cases of osteoarthritis of the hip were observed in a survey of 155 gorilla skeletons examined in six anatomic collections or museums.

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Osteoarthritis Coxal in un Gorilla
Reporto de un Tertie Caso

Summario in Interlingua

Es describite un tertie caso de osteoarthritis del coxa in un skeleto de gorilla. Le documentation include photographias e *roentgenographias. Il se tracta de un gorilla* feminin adulte. Le coxa interessate es le coxa dextere. Le acetabulo es allargate e pauco profunde. Le tecto es oblique. Neoformation de osso abunda al circumferentia e resulta in un incisura claudite. Le capite del femore es allargate, applanate, e perforate per numerose micro-aperturas. Le cervice es multo curte, de maniera que le capite reposa quasi super le diaphyse. Illo es displaciate in senso distal. Le deformitate del acetabulo es monstrate in un radiographia. Le angulo CE de Wiberg es reducite a zero al latere afficite, durante que illo mesura 25 grados al latere normal.

Le caso es comparate, super le base de mesurationes e radiographias pelvic, con duo alteres que esseva reportate in 1955. In iste previe casos il se tractava de adultos mascule. Le coxa interessate esseva le coxa *sinistre. In* ambe casos le lesion esseva attribuite al effectos tardive de morbo de Legg-Calvé-Perthes o a glissage de epiphyse. Le comparation monstra que le tres casos differe e solmente in le grado del severitate. Un revista del datos e le determination del angulos CE suggere que omne le tres esseva causate per dysplasia congenite.

Iste deformitates esseva probabilemente dolorose e partialmente invalidante, sed proque le gorilla vive al fundo del jungla sin multe inimicos natural e proque illo es un vegetariano absolute que non debe capturar victualias vive, illos non preveniva un disveloppamento normal e le superviventia del patientes usque al maturitate.

28

Sarcoma Following a Surgically Treated Fractured Tibia

A Case Report

EDUARDO R. DELGADO, M.D.*

A white male, 40 years old, presented himself at the clinic with a history of a fall 3 years previously, when his leg had been struck by an iron tube. At that time he went to a hospital and was operated upon for fractured tibia. Osteosynthesis with plate and screws was performed (Fig. 1). He used a cast for 3 months and then was discharged with slight edema of the leg. He did fairly well for the first two years, but the last year, he had pain on walking and the trouble recurred. In these circumstances the removal

* Havana, Cuba.



FIGURE 1

FIGURE 2

of the plate and the screws was recommended, and the procedure was carried out (Fig. 2). At surgery a firm consistent mass around the area of fracture was found, and biopsy was taken. The section showed areas of osteoid tissue partially calcified, and a diagnosis of periosteal ossification was made (Fig. 3). The patient left the hospital on October 20, 1956, and on November 27 was seen again. At that time the roentgenogram showed an increased periosteal reaction (Fig. 4, *left*). The patient received deep x-ray therapy to a tumor dose of 1,000 r and left the hospital on December 22, 1956.

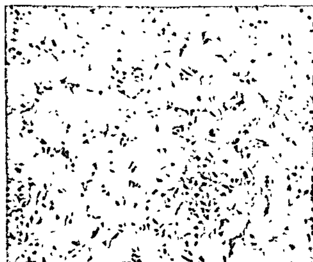


FIGURE 3

On January 2, 1957, the patient was seen again, and the roentgenogram showed an increase in the mass around the tibia (Fig 4, *right*). On January 12, 1957, he was operated upon, and a second biopsy was done. Malignancy was evidenced by sarco-

FIGURE 4

matous areas, cartilage and osteoid formation and mitotic figures (Fig. 5) On January 23, 1957, an amputation was performed through the distal femur (Fig 6, *left*) The specimen showed a big tumor mass at the distal portion of the tibia. The tumor was firm, pinkish white in color with hemorrhagic areas

The roentgenogram of the lungs was negative when the patient left the hospital.

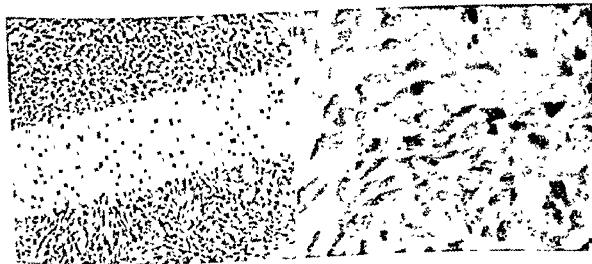


FIGURE 5

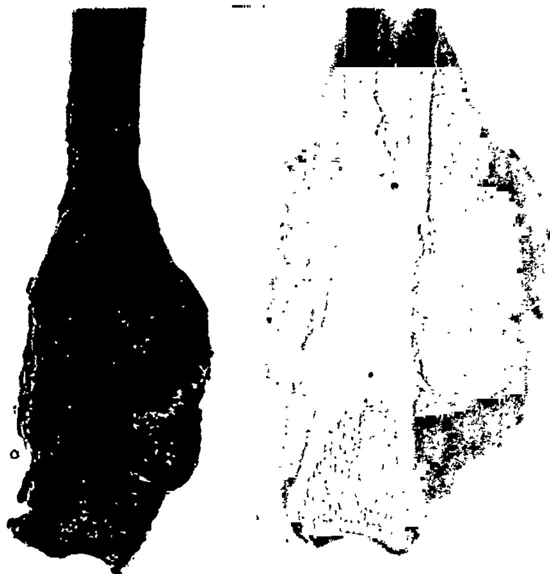


FIGURE 6

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